MEDICAL ELECTRICITY

LEWIS'S PRACTICAL SERIES

LEWIS JONES


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LEWIS'S PRACTICAL SERIES.

MEDICAL ELECTRICITY.

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A

PRACTICAL HANDBOOK

FOR

STUDENTS AND PRACTITIONERS

BY

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BEING THE THIRD EDITION OF "MEDICAL ELECTRICITY," BY W. E. STEAVENSON, M.D., AND H. LEWIS JONES, M.D.

WITH ILLUSTRATIONS

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PREFACE TO THE THIRD EDITION.

THE whole of the matter has been carefully revised in this edition and sixty fresh pages have been added.

The utilisation of current from the mains for medical and surgical purposes is now given a separate chapter. The chapter on statical electricity has been re-written and brought up-to-date. The uses of the electric bath and arm-bath are treated more fully than before, and a short chapter on X ray work has been added at the end of the book.

I wish to record my indebtedness to the *Archives d'électricité médicale*, and to Professor Bergonié, its able editor, for many valuable papers and references.

In an appendix will be found a list of towns and places having a public electric light supply, with some details of the character of the current furnished.

61 Wimpole Street.

May, 1900.

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MEDICAL ELECTRICITY.

CHAPTER I.

HISTORICAL.

Origin of the word Electricity. Dr. Gilbert of Colchester. Early medical writers. Remak and Duchenne. Position of electricity in medicine.

1. **Origin of the word electricity.**—The foundation of the modern science of electricity may be considered to have been laid by a medical man, Dr. Gilbert of Colchester, Physician in Ordinary to Queen Elizabeth and President of the Royal College of Physicians in the year 1600, the date of the publication of his treatise *De Magnete.*

He extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems also that we owe to him the word Electricity, for he called all those substances Electrics, which when rubbed displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

Dr. Gilbert does not seem to have attempted to apply his knowledge of electricity in any way to medicine, but he will always be remembered as the pioneer in the

scientific investigation of electricity and magnetism. Dryden has immortalised him in the following lines :—

> "Gilbert shall live till lodestones cease to draw
> And British fleets the boundless ocean awe."

2. **Early medical writers.**—It was more than a hundred years after Gilbert's time that electricity was first brought into use as a curative agent, and in the early applications of electricity to medicine the statical apparatus was the only form used because it was the only one known, but for many years after the discoveries of Galvani and Volta statical electricity still remained in exclusive possession of the field of electro-therapeutics.

De Haen (1745) Jallabert (1748) and the Abbé Nollet (1749) were the first to apply statical electricity to medicine.

In 1758, Benjamin Franklin relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from various parts of Pennsylvania and the neighbouring provinces.

In 1759 the Rev. John Wesley, the famous divine, collected a number of cases in which electricity had been tried, and published a treatise entitled *The Desideratum, or Electricity made Plain and Useful, by a Lover of Mankind and Common Sense.* In this are given the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passage of calculi through the ureters. He also relieved tertian and quartan fevers, and hysteria.

In 1773, Manduyt published a work on statical electricity.

In 1777, Cavallo published in London a complete treatise on electricity in theory and practice, with ori-

ginal experiments. It included general remarks relating to Medical Electricity.

The first records of electrical treatment at a London hospital seem to have been in the year 1767, when an electrical apparatus was ordered for the Middlesex Hospital. And ten years later, in 1777, an electrical machine was purchased for the use of the patients in St. Bartholomew's Hospital.

A letter on the subject of medical electricity by Mr. John Birch, Surgeon, is to be found in a book called *An Essay on Electricity*, by John Adams. The fifth edition of this book was published in 1799, and in it Birch's letter occupies fifty pages. He was attached to St. Thomas's Hospital, where he had charge of the electrical department.

In England in the earlier half of the present century the work of Addison (1837) Golding Bird (1841) and Gull (1852) at Guy's Hospital must be noted. Accounts of what was done by them may be found in the Guy's Hospital Reports for those years, or in Dr. Monell's* book in which they are reproduced in a slightly condensed form.

Golding Bird also published some lectures on Electricity and Galvanism in 1849, and this marks the transition period from the dominance of Statical Electricity in therapeutics to that of battery and induction coil currents. In England since that time little or nothing has been done with statical electricity in medicine, although M'Clure of Cromer wrote on the subject in 1889.

3. **Remak and Duchenne.**—Remak in Germany and Duchenne in France laid the foundations of the

* "Manual of Static Electricity in X Ray and Therapeutic Uses." S. H. Monell, M.D., New York, 1897.

modern modes of treatment by the battery (galvanism) and the induction coil (faradism). Both were eminent men ; but the latter especially has left his mark upon modern work in medical electricity. It is to Duchenne* that we owe the principle of applying the currents directly to the affected nerves or muscles. Duchenne also showed that the muscles could be most easily excited at certain points of the surface, which he called *points d'election*. These points where shown by R. Remak and von Ziemssen to be the places nearest to which the motor nerves enter the muscles. They are now called "the motor points." (Chap. VII.).

About 1850 great advances were made in our knowledge of electro-physiology. Du Bois Reymond and Pflüger demonstrated the electrical phenomena of living nerve and muscle, and established the laws of electrotonus, the phenomena of the contractions of muscle, and the existence of muscle currents. Remak wrote upon the catalytic effects of the galvanic current, viz , upon the use of continuous currents for the relief of congestions and chronic inflammatory processes, effects which we should now probably speak of as due to an action upon the circulation. Our present modes of application of electricity in medicine have been built upon the investigations of Duchenne, Remak, Brenner, von Ziemssen, Boudet de Pâris, Onimus, Erb, De Watteville, D'Arsonval, and many others of note.

4. **Position of electricity in medicine.**—It is now one hundred and fifty years since the beginning of Medical Electricity. During the whole of that time it

* "De l'electrisation localisée, et son application à la pathologie et à la therapeutique, par courants induits et par courants galvaniques, interrompus et continus." (Translated in an abridged form for the *New Sydenham Society* by Dr. G. V. Poore).

has had to fight its way step by step in the face of many difficulties, and the most serious of them all has been the passive resistance of medical men themselves. The vitality which it has shown under adverse circumstances is full of good omen for the future. Medical electricity is advancing and will continue to advance indefinitely. To those who have followed its developments the progress achieved in the past decade is enormous. The house to house distribution of electricity by Electric Light Companies has called into existence a large number of new instruments and methods, and is helping to break down the idea that electrical apparatus is difficult to keep in order by providing a constant and steady supply of current without the need of batteries. The introduction of the secondary cell or accumulator into general use has also been of great service by affording a simple means of obtaining electrical currents for the use of surgeons. Further, the notion of the treatment of disease by physical means is becoming a more familiar one among medical men, and it is recognised that patients often need something more than they can obtain from drugs alone. Baths, active exercises, passive exercises, massage and shampooing, sunlight and exposure to the open air are all called in to-day as healing agents. Considerable advances have been made lately towards the recognition of the good effects of electricity in general therapeutics, as distinguished from its use for merely local applications, and it is now clear that the "localised electrisation" of Duchenne and of his school covers only a part of the ground belonging to medical electricity.

The discovery of the X rays and the practical applications of them to medicine and surgery which immediately followed, have also done good to the cause of

medical electricity, by bringing electrical apparatus into more extended use among professional men, and the founding of X ray departments in Hospitals may lead to the association with them of proper electro-therapeutic departments, in places where these are not already in existence. Most of the London Hospitals now have an electrical department more or less efficiently equipped, and these are of manifest utility. At St. Bartholomew's Hospital over six hundred new patients are referred yearly to the electrical department from all quarters of the hospital.

There are signs, too, of a revival of statical electricity which has been absolutely and totally neglected in England since the times of Addison, Golding Bird and Gull, with the exception of the work done by Dr. M'Clure of Cromer. In France, in the United States, and elsewhere, the statical machine has commanded a good deal of attention lately, and great progress has been made in America in the construction of large machines for therapeutic purposes, while the technical details of using these instruments have also been carefully studied, with a result that the statical apparatus is again taking an important place in electro-therapeutics.

CHAPTER II.

Fundamental Experiments and Definitions.

Fundamental Experiments. Hypotheses of Fluids. Electroscopes. Conduction. Electric Quantity. Electromotive Force. Potential. Electrometers. Electric Density. Capacity. Condensers. Leyden Jar. Contact electromotive force. Simple Voltaic cell or battery. Oersted's experiment. Magnetic field. Galvanometers. Electromotive force. Resistance. Ohm's Law. Practical units. Specific resistance. Measurement of resistance. Electrolysis. Resistance of an electrolyte. Electromagnetic induction.

5. **Division of the subject.**—It is usual for medical men to speak of electrical effects as if they were due to no less than three distinct kinds of Electricity. These we are accustomed to call "Statical Electricity," "the Continuous or Galvanic Current" and "the Interrupted or Faradic Current." This division, however convenient it may be for purposes of medical treatment, has nothing to recommend it when the subject is looked at from a scientific point of view. The Science of Electricity may best be divided into four branches as suggested in Dr. Oliver J. Lodge's "Modern Views of Electricity," a book which should be read with care by everyone who wishes to have definite and correct notions concerning the science. These four divisions are:—

a. Electricity at Rest, or Static Electricity.—This branch coincides with that portion of the science generally treated of as "Frictional" Electricity.

b. Electricity in Locomotion, or Current Electricity.—This includes the consideration of the continuous current and of the interrupted current.

c. Electricity in Rotation or Magnetism.

d. Electricity in Vibration or Radiation, a branch of the subject treated of in general in that section of Physics which deals with the phenomena of Light.

We only need to consider at all fully the two first of these branches, and of these more especially the second. In the third branch we shall have to touch slightly upon magnetism in order to make clear the nature and principles of certain electrical measuring instruments.

The fourth branch is now coming into the sphere of practical utility through the employment of electric radiations for the transmission of signals to a distance without wires. In the public mind this is associated mainly with the name of Signor Marconi, but the discovery of electric radiation and the first demonstrations of the transmission of electric waves to a distance without wires, were the work of Professor Hertz. Electricity in radiation is also concerned in the phenomena of the X rays.

6. **Fundamental experiments.***—If a piece of glass and a piece of resin be taken they neither attract each other nor any light bodies to which they may be presented. If now they be rubbed together, so long as they are not separated, they still display no powers of attracting light bodies, but let them be separated and they are at once seen to be endowed with the power of attracting each other, and each is capable of attracting light bodies. They are said to be electrified. If a

* "On the Mathematical Theory of Electricity in Equilibrium." Sir W. Thompson's papers on "Electro-Statics and Magnetism," p. 43. Maxwell's "Electricity and Magnetism," vol. i., p. 31.

second pair of pieces of resin and glass be taken, rubbed together and then separated, it may be seen—

a. That the two pieces of glass repel each other.

b. That each piece of glass attracts each piece of resin.

c. That the two pieces of resin repel each other.

The two pieces of glass are said to be oppositely electrified to the two pieces of resin, and we can observe as a definition that similarly electrified bodies repel each other, oppositely electrified bodies attract each other. These electrifications are known as *vitreous* or *positive* and *resinous* or *negative.* We also observe that since the rubbed glass and resin before being separated exhibited no powers of attraction or repulsion on external bodies the amount of electrification produced on the glass exactly neutralizes the effect of and therefore is equal and opposite to that produced on the resin.

It should here be noticed that an electrified body exerts no force on any non-electrified body, but that when it appears to do so as in the case in which rubbed glass or resin was seen to attract light bodies, the electrified rubbed substance first acts on the neutral bodies and electrically excites them by its influence or "inductively" (*see* § 11), so that the attraction shown is not an action between an electrified body and neutral matter, but between two electrified bodies.

7. **Hypothesis of fluids.**—Various hypotheses have been put forward to account for this action, all of which more or less fail to do so; two of these may, however, be noticed, more especially as, if cautiously used, they supply a convenient means for clearly expressing electrical facts, though it must always be carefully remembered that in using these modes of expression we are making no assumptions as to the truth or the reverse of the

hypothesis, but merely using a convenient analogy. The first is the "two fluid" theory of Symmer in which it is assumed that all matter contains an inexhaustible supply of a so-called electric fluid which is capable of being split up by friction or otherwise, into equal quantities of two fluids of opposite properties, viz., the so-called vitreous (positive) and resinous (negative) electricities, and bodies that display the properties that we have said are signs of electrification, are said to be charged with a certain quantity of one or other of these fluids, a certain quantity of positive or negative electricity. This hypothesis gives us in many cases a convenient method of expressing the facts, provided always that it be used as such, and is not pushed to the point of considering that the electric fluids are any real entities or have any actual existence. It is obvious that it is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

In the "one fluid" theory which was favoured by Franklin, bodies that were positively electrified were looked upon as containing an excess of electric fluid, bodies that were negatively electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency.

8. **Electrics and non-electrics.**—All bodies when rubbed with suitable precautions are to use Gilbert's term, *electrics*, or rather we should say, that whenever any two bodies are rubbed together electrical separation occurs, one body becoming positively and the other negatively electrified, although in many cases it is difficult to observe this owing to the escape of the charge by conduction or otherwise, and in fact it is possible to arrange all substances in a list, so that when any pair

of them is rubbed together, the body higher in the list is positively electrified, while the other is of course negatively electrified to an equal extent.

Such a list is as follows :—Cat's fur, polished glass, flannel, leather, wood, paper, silk, shellac. Thus :— Glass rubbed with cat's fur will be negatively or resinously electrified, while the same glass rubbed with silk will be positively electrified.

Any instrument by which electrical separation is produced may be called an electrical machine. For simple experiments, a glass rod which is rubbed with a piece of silk on which has been smeared some electrical amalgam* is such a machine. Some more elaborate electrical machines will be fully described in a future chapter.

9. **Electroscopes.**—Before going any further it is necessary to consider some means by which we may tell when a body is electrified. Instruments for this purpose are called electroscopes, or sometimes more loosely electrometers. The simplest form of electroscope is that known as the gold leaf electroscope, which is made of two strips of gold leaf hung together from a wire. When these are electrified they repel each other and diverge, and so indicate the presence of electrification. The instrument is usually enclosed in a glass jar which serves as a support and protects the gold leaves from disturbances by currents of air. (Fig. 1). This figure represents the instrument in its simplest shape, but many elaborated and improved forms have been devised.

It is easy with this instrument to discern the sign of the charge on any electrified body, for if a portion of

* Electrical amalgam is made of tin one part, zinc two parts, and mercury six parts. (Tyndall's "Lessons in Electricity," p. 7).

the charge be transferred to the electroscope and an additional charge be added from a vitreously electrified body, *e.g.*, from a glass rod that has been rubbed with silk, then if the former charge was negative the leaves will collapse, but if positive they will diverge still further.

The best way of carrying out this test is as follows:—Approach the charged body to be tested to the electroscope. The leaves will diverge. Touch the plate of

FIG. 1.—Stewart's Gold Leaf Electroscope.

the electroscope with the finger for an instant and they will collapse, but on subsequently removing the body to be tested, they will again diverge under the effects of a charge of opposite sign to that of the body to be tested. Now bring up near the electroscope a rubbed glass rod, if the leaves collapse the present charge is negative, and that of the original charged body was therefore positive.

The reasons for this procedure will be understood from the next paragraph but one.

10. **Conduction.**—Let any body, for instance a metal sphere, be electrified, taking care that it is supported by silk strings or by a glass stem. Let it be connected with another similarly supported non-electrified body by means of a wire for an instant. Now let the second body be examined with the electroscope; it will be found to be electrified in the same sense as the first body but to a less degree; the charge of the first body has been partly conducted along the wire connection and has been divided between the two bodies. If connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is therefore a *conductor* of electricity, the glass rod, &c., are not, they are *insulators*. This experiment explains why it was necessary to support the charged bodies we have been dealing with by silk threads, it also explains how it was that all the electrics known to the ancient electricians were insulators or non-conductors of electricity, since though conductors can be readily excited by rubbing with proper substances, special means must be taken to insulate them that the charge may not leak away before the electrification can be observed.

Substances vary very much in their power of conducting electricity, thus metals are good conductors, water and the body are fairly good ones, wood and cotton are poor conductors, while wool, silk, oils, resins, dry air, and most kinds of glass are good insulators.

11. **Induction.**—"A conductor can be electrified either by a transfer of electricity between it and another conductor, or by an alteration in the distribution of the electricity on its surface, without any transfer of electri-

city between it and another conductor. In the former case the body is said to be electrified *by conduction*, in the latter *by induction* or *inductively*.

Take a hollow metal vessel, insulate it by hanging it up by silk threads, and connect it with an electroscope.*

If the vessel be unelectrified and we introduce into it an electrified body, taking care not to touch the sides of the vessel so that no charge passes from the electrified body to the vessel, the electroscope will indicate a charge, and on being tested it is found to be a charge of the same sign as that on the charged body introduced into the vessel, *e.g.*, if the charged body is a piece of rubbed glass, the electroscope will indicate positive electricity. If now it be removed without having touched the interior of the vessel, the leaves of the electroscope will collapse, and the vessel will be left without charge, if, however, it has been allowed to touch the vessel, the leaves will remain divergent, but the body will be found to be completely discharged.

In the first case the vessel is said to be electrified by induction, and from the second case we see that the observed induced electrification is exactly equal to, and is of the same sign as that of the inducing body. Had we momentarily connected the vessel to earth so as to discharge the first induced electrification, and then removed the charged body without touching the vessel, the vessel would be found to be charged with the opposite kind of electricity to as great an extent as in the first case. Similar effects are produced whenever an electrified body is brought near any other body, and this is what was referred to in § 6, when it was stated that the light bodies apparently attracted by an electri-

* Faraday's "Experimental Researches on Static Electrical Inductive Action." Maxwell's "Electricity and Magnetism," vol. i., p. 32.

fied glass rod, &c., were first electrified by its influence. In the language of the two fluid theory an electric charge in any body reacts on the neutral fluid in the bodies near it, attracting towards itself an equal quantity of the fluid of opposite sign and setting free an equal quantity of the fluid of similar sign to itself. This is generally illustrated diagrammatically by considering the side of the body nearest to the glass rod as charged with − electricity and the opposite side charged with + electricity, the attraction thus overbalancing the repulsion.

"Acting inductively on an uncharged conductor produces no charge on it as a whole, but merely induces equal and opposite charges on its two sides or ends."*

12. **Electric quantity.**—Hitherto in this chapter the consideration of quantity of electricity has been left in the background, and electrification has been spoken of rather as a state or quality super-induced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measurable quantity, *i.e.*, as brought about by the presence of a real or hypothetical something which can be measured and which is called electricity, a something which has been referred to for convenience sake in the language of the "fluid" hypothesis as if it were an actual fluid, but which, it must be borne in mind, is not that, whatever else it may be. Let us suppose the existence of a something which is measurable and which when present in any body endows it with the properties just described under the name of electrification, and which is called Electricity. This electricity then is of two kinds, one named positive or vitreous, and one negative or resinous. It has been seen already that positive electricity repels

* Ayrton, "Practical Electricity," p. 97.

positive, and that negative repels negative, while positive electricity attracts negative and *vice versâ*. This has to be expressed in terms of some unit, to be chosen once for all.

*Unit of Quantity.**—That quantity of electricity, which when supposed collected at a point will repel an equal quantity of similiar electricity collected at a point, and placed at unit distance from the first, with unit force shall be taken as the unit quantity of electricity.

Now in this definition the unit quantity of electricity is made to depend on the units of length and of force, and this latter is defined with reference to the units of length, mass and time. Hence the unit quantity of electricity has been completely defined in terms of the units of length, mass and time. For scientific purposes these are taken as one centimetre, one gramme and one second respectively.

There is one matter that has not explicitly been taken into consideration in thus defining the unit quantity of electricity, viz., the medium in which the action between the two charges takes place. It is assumed, however, that this is air, or more strictly speaking, a vacuum.

Now the attraction or repulsion between two quantities of electricity is proportional to each, *i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always of course supposing that the two quantities are collected at two points.

13. **Electromotive force, potential.**†—" Whatever produces or tends to produce a transfer of electrification is called *electromotive force*. Thus when two

* Maxwell's " Electricity and Magnetism," vol. i., p. 44.

† Quoted from Maxwell's "Elementary Treatise on Electricity," p. 5.

electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which when the wire is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire.

"To define completely the electromotive force from one point to another, it is necessary in general to specify a particular path from the one point to the other along which the electromotive force is to be reckoned. In many cases, *e.g.*, in electrolytic, thermo-electric and electro-magnetic phenomena, the electromotive force from one point to another may be different along different paths; if we restrict our attention, however, as we must do in this part of our subject, to the theory of the equilibrium of electricity at rest, we shall find that the electromotive force from one point to another is the same for all paths drawn in air from the one point to the other.

"The electromotive force from any point along a path drawn in air, to a certain point chosen as a point of reference, is called the *electric potential* at that point.

"Since electrical phenomena depend only on differences of potential, it is of no consequence what point of reference we assume for the zero of potential, provided that we do not change it during the same series of measurements.

"In mathematical treatises, the point of reference is taken at an infinite distance from the electrified system under consideration. The advantage of this is that the mathematical expression for the potential due to a small electrified body is thus reduced to its simplest form.

"In experimental work it is more convenient to

assume as a point of reference some object in metallic connection with the earth, such as any part of the system of metal pipes conveying the gas or water of a town.

"It is often convenient to assume that the walls, floor and ceiling of the room in which the experiments are carried on have conducting power sufficient to reduce the whole outer surface of the room to the same potential. This potential may then be taken for zero. When an instrument is enclosed in a metallic case the potential of the case may be assumed to be zero.

"If the potentials at different points of an uniform conductor are different there will be an electric current from the places of high to the places of low potential. At present we are dealing with cases of electric equilibrium in which there are no currents. Hence in the cases with which we have now to do the potential at every point of the conductor must be the same. This potential is called the potential of the conductor.

14. **Physical analogies.**—"The idea of electrical potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in which it is less till the pressure is equalised. This, however, will not necessarily be the case if one vessel is higher than the other, for gravity has a tendency to make the fluid pass from the higher to the lower vessel. Similarly when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential. Again if two bodies at different temperatures are placed in

thermal communication, either by actual contact or by radiation, heat will be transferred from the body at the higher temperature to the body at the lower temperature, till the temperature of the two bodies becomes equalised. The analogy between temperature and potential must not be assumed to extend to all parts of the phenomena of heat and electricity. We must also remember that temperature corresponds to a real physical state, whereas potential is a mere mathematical quantity the value of which depends on the point of reference we may choose. To raise a body to a high temperature may melt or volatilize it, to raise a body, together with the vessel which surrounds it, to a high electrical potential produces no physical effect whatever on the body. Hence the only part of the phenomena of electricity and heat, which we may regard as analogous, is the condition of the transfer of heat or of electricity according as the temperature or the potential is higher in one body or in the other. With respect to the other analogy—that between potential and fluid pressure—we must remember that the only respect in which electricity resembles a fluid is that it is capable of flowing along conductors as a fluid flows in a pipe."

In terms of this analogy the electricity is compared to the fluid, while the pressure of the fluid at any point answers to the potential of the electricity at a corresponding point, the difference of pressure between two points causes the flow of fluid from one to the other, while similarly the electromotive force or difference of potential between two points causes the flow of electricity from one to the other.

The conception of electric potential is a very difficult one, and this is not the proper place for a discussion of it in all its bearings ; enough has been said in the long

quotation from Clerk Maxwell to give some idea of the meaning of the word, but the student who wishes to obtain a thorough insight into it cannot do better than read Clerk Maxwell's *Elementary Treatise on Electricity*, giving special attention to Chapter III., on "Electrical Work and Energy." In most of what follows, and especially in the part which refers to electricity in motion, the idea of electric pressure in connection with the word potential will be the dominant one; but it must always be remembered that this idea of pressure is based on the analogy of the electric flow to a fluid flow, and this is at best very imperfect.

15. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instruments, just in the way that a quantity of water driven through a water meter can be measured, and some of these instruments will be discussed in a future chapter; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential.

The gold leaf electroscope has been shortly referred to above. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, or way by which electricity enters the instrument, is at a different potential to the walls of the room, or to that of the metal cage that surrounds some forms of the instrument, but obviously without further observation it does not tell whether the potential is higher or lower, *i.e.*, more positive or more negative, and further tests must be made to discover this. Neither does it give us more than the roughest indication of the amount of

difference of potential. In cases where there is a great difference of potential, and a delicate gold leaf electroscope is likely to be spoilt, rougher forms may be used, *e.g.*, Dutch metal or even pith balls suspended by linen threads may be used instead of the more delicate gold leaf.

If it is required to measure a difference of potential an *electrometer* must be used. There are many forms of these, most of which are due to the inventive genius of Lord Kelvin. Descriptions of the various forms will be found in most text-books, such as for instance in S. P. Thompson's *Lessons in Electricity and Magnetism*, or the article "Electrometer" in the last edition of the *Encyclopædia Britannica;* but best of all in Sir W. Thomson's papers on *Electrostatics and Magnetism*, pp. 263, *et seq.*

16. **Distribution of charge; Density.**—It has been observed that the whole of an electric charge resides on the surface of a charged conductor, and this has been proved by direct experiment in many ways. It is found that while the distribution over a sphere is uniform, as might be expected from the symmetry of the figure, it is not so on conductors of other shapes. On these the charge per unit of surface, which is called the density, is greater the greater the curvature of the surface till at a sharp edge or a point the density becomes so great that at high potentials a discharge takes place. For this reason if a point is attached to a highly charged conductor a stream of charged particles of air is repelled from the point giving rise to a wind setting from the point and rapidly discharging the conductor.

17. **Action of points.**—This action of points becomes of great importance in some electrical machines,

and in some kinds of electrical treatment. In the first place the presence of a point on a charged conductor renders it difficult to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor; for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralising its positive charge, and leaving the conductor which bears the point positively charged if it is insulated. It is by this means that the prime conductors of most electrical machines are charged from the excited plate or other moveable part.

18. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is called its *Capacity.*

As the charge resides only on the surface of a charged body, the capacity of a conductor is determined by the extent of its surface, and a body of a large surface has a larger capacity than a body of smaller surface.

When a conductor is said to have a given capacity, it must not be thought that the conductor can hold only a certain fixed charge, in the way in which a bottle can be said to hold only so much water, because the quantity of electricity that can be put into a conductor of a certain capacity depends upon the potential or pressure at which it is charged. A body of unit capacity holds unit quantity when charged to unit potential, and holds ten times as much when charged to ten times the potential. On this account it is necessary to know both the capacity of a conductor, and the potential to

which it has been charged, before forming any idea of the quantity of electricity which it contains. The capacity of a conductor may be compared to the capacity of an elastic bag. The amount of air or of water that can be forced into an elastic bag depends upon the pressure at which it is forced in, and provided the bag does not burst, it can be made to hold more and more by increasing the pressure at which it is charged.

The capacity of a conductor is increased by bringing near to it other conducting bodies, which are maintained at zero potential by being connected to earth, and it may be stated generally that the nearer the "earthed" conducting bodies are to a conductor the greater becomes the capacity of that conductor.

The importance of this point is well brought out by an example. The capacity of a sphere of ten centimetres radius suspended freely in space is ten units, but if another sphere of eleven centimetres radius be placed concentrically to it, so that the two spheres are separated one from another all round by one centimetre of air, and if the outer sphere be maintained at zero potential by connection to earth, then the capacity of the inner sphere is no longer ten, but 110 units, while if the radius of the outer sphere be reduced to ten and a half centimetres, the capacity of the inner one would become 210 units.*

19. **Condensers.**† An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected

* If a be the inner and b the outer sphere, then the capacity of a is given by the formula $\frac{ab}{b-a}$.

† Maxwell's *Elementary Treatise on Electricity*, Chap. VIII.

to earth, a small electromotive force is able to charge the other with a much larger quantity of electricity than if it stood alone, *i.e.*, its capacity is increased by the proximity of the other conductor.

The simplest form of condenser consists of two metallic discs supported on insulating stems and facing each other, the intervening non-conductor or *dielectric* being air. If now a different dielectric, as for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different and greater than before, thus the action across the dielectric depends on the nature of the dielectric.

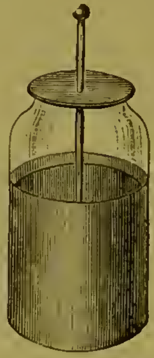


FIG. 2.—Leyden jar.

Since a glass condenser has a higher capacity than an air condenser, glass is said to transmit induction better than air, or in other words, glass has a higher *dielectric constant* or *specific inductive capacity* than air.

20. **Leyden jar.**—The electrical condenser most often used in experiments on static electricity is that known as the Leyden jar (fig. 2).

The ordinary form of this apparatus is a glass jar or bottle coated inside and out with metal foil to within two or three inches of the top. Through the cork of

the bottle a wire passes, terminating above in a knob, and below in a chain to make metallic contact with the inner coating. To charge the jar the outer coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine. The charge given to the inner coating acts inductively upon the outer coating across the dielectric of the jar, which is thus able to retain its charge. It may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur and the jar is discharged.

The capacity of a Leyden jar depends upon the area of the surfaces coated with tinfoil, and also from what has been said in § 18, upon the thinness of the glass of which it is made. If the glass be very thin it may give way under the strain when charged to a high potential, and be broken to pieces.

21. **Contact electromotive force.**—It was observed at the end of the last century by Volta, that when dissimilar metals, such as zinc and copper, were brought into contact in air, electrical separation took place, and a small difference of potential was set up between the metals, the zinc being positive to the copper, or at a higher potential. Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals, as a difference of potential between two parts of a homogeneous conductor would do, because the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in which it tends to cause a flow, but that is absurd. But if the two pieces of metal while in contact are immersed in some liquid that is

capable of acting chemically on one of them, *e.g.*, dilute sulphuric acid, a complete "circuit" is formed, and the discharge can take place through the liquid, which undergoes decomposition thereby, and the difference of potential being continually renewed at the expense of the chemical energy caused by the action of the liquid upon the zinc plate, a continuous discharge takes place round the circuit in the following way:—

Positive electricity passes across the junction of copper and zinc, and then from the zinc across the liquid to the copper again. If the connection of copper to zinc be by a wire, as is usually the case, we may use the language of the two-fluid hypothesis and look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from zinc across the liquid or electrolyte to copper and back to the zinc again along the metallic connection between it and the copper, thus making a true circuit.

22. **Voltaic cell.**—Such an arrangement is called a voltaic cell, and but for disturbances that will be more fully considered in Chap. III., it would give a continuous current, till either the zinc or the exciting liquid (called the *electrolyte*) was exhausted. The difference of potential in a cell, or its *electromotive force*, is due to the contact electromotive force of the metals forming the poles of the cell, though in certain cases this may be slightly modified by the liquid used. It is possible to increase the electromotive force by joining together a sufficient number of simple voltaic cells, zinc of one to copper of the next. Such a combination of cells is called a battery, and the cells are said to be joined *in series;* and the electromotive force of the battery is equal to the sum of the electromotive forces of the cells which compose it.

It is customary in some textbooks to speak of the zinc plate of a battery as the positive plate, and the copper or other plate as negative, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is no doubt the fact that in the battery the positive direction of flow of the current is from zinc to copper, and that zinc is said to be electro-positive to copper. But in the connecting wire the positive direction of flow of the current is from copper to zinc (see fig. 3), and as this is the

FIG. 3.—Single voltaic cell showing poles and direction of flow inside and out of cell.

portion of the circuit that we are most concerned with, the word positive will be used to denote the positive pole of the battery and also the plate connected with it, when it is necessary to specify this. This is in conformity with the usage of electrical engineers, who speak of the peroxide plates in an accumulator as "positives."

23. **The magnetic needle.**—When a magnet is suspended freely at the surface of the earth it is found that it swings so as to set itself with one pole pointing towards the North (or at least approximately so) and

the other towards the South. The poles are spoken of as the *North seeking* and *South seeking* poles respectively, and their names are abbreviated into N. and S. for convenience.

24. **Oersted's experiment.**—Let a small magnet, say a compass needle, be suspended freely at rest. It will point North and South, now over it let there be carried a wire joining the two terminals of a Voltaic cell or battery in such a way that its course from copper to zinc along the wire shall be from South to North, *i.e.*, so that the current (the positive direction of flow) is from South to North, then the North seeking end of the magnet will be deflected towards the West. This observation is due to Oersted of Copenhagen, and it was formulated by him into a law for telling the direction of flow in a circuit, thus:—Imagine a man swimming with the current in the wire, *i.e.*, from copper to zinc and facing the needle, the North seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

25. **Magnetic field. Lines of force.**—The region of space about any magnet and throughout which we consider its action is called its *field*, and lines of magnetic induction or lines of force round a magnet can be mapped out. These will then all start from points or surfaces indued with N magnetism and end in points or surfaces indued with S magnetism, and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per unit of surface at right angles to them at that point.

It is easy to map the field of force round any magnet, since every magnet tends to set itself parallel to the lines of force at the point where it is. If then the mag-

net whose field is to be mapped be laid down on a sheet of white paper, and a small compass needle be moved about in its vicinity, the direction of the needle at any point will give the direction of the lines of force at that point and these can be plotted on the paper. And soft iron filings, in a magnetic field, become magnets themselves by induction, and so set themselves along the lines of force, mapping them out to the eye in a very beautiful manner.

If a sheet of paper be laid down over a bar magnet, and iron filings be sifted over the paper, and the paper be gently tapped, they will arrange themselves into a figure composed of curved lines which emerge from one pole, and pass round to converge at the other (see fig. 4).

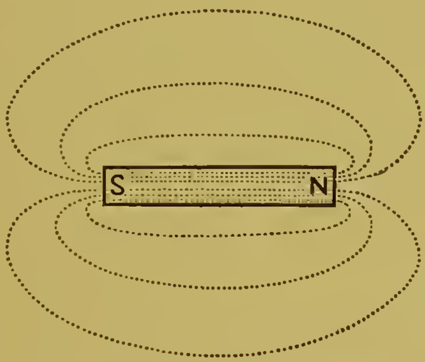


Fig. 4.—Lines of force of a bar magnet.

26. **Field of force about a wire carrying a current.**—To return to the electric current. We can now draw a deduction from Oersted's experiment (§ 24), viz., that there must be a magnetic field of force about every wire that is carrying a current, and since, when we are facing the magnet and swimming with the current, the N pole is always deflected to the left whatever

the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card, through a hole in which a vertical wire carrying a moderately strong current is passed; when the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles round the wire; also if we look along the wire from copper to zinc, *i.e.*, with the current, the direction of the lines, the direction in which a N pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle due to the current at all points of the arc. If the arc were in the plane of the paper and the current ran counter clock-wise in it, the direction of the lines of force would be vertically up from the paper.

27. **Galvanometers.**—Oersted's discovery enables us to make an instrument for measuring the current in any circuit. Such an instrument is called a *galvanometer;* or when, as is frequently the case, it is used merely to indicate the presence of a current it may be called a *galvanoscope.*

In its simplest form, stripped of all non-essentials, the galvanometer consists of a coil of one or more turns of wire with a small magnet suspended freely at the centre. The coils may be, and generally are, circular, but frequently for convenience of construction or other reasons they are wound in other shapes. The needle being suspended freely sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle and therefore to the magnetic field at the place. Hence the field due to a

current circulating in the coils will be at right angles to the permanent field with which it is to be compared and will tend to deflect the needle.

In order to read the deflections of the needle when the galvanometer is in use, one of several devices may be applied. The simplest, where very accurate reading is not essential, is to attach to the needle a light pointer which passes over a scale.

By multiplying the number of turns of wire in the galvanometer coils the action of the current on the needle becomes increased in proportion, each turn exercising its own effect. On this account the name of "multiplier" was once given to the galvanometer. But it must not be forgotten that if the number of windings be largely increased, an obstacle to the passage of the current, or a *resistance* is thus introduced, which may have the effect of largely diminishing the current flowing through the coils. It is therefore necessary to wind galvanometer coils so as to suit the special purposes for which they are intended to be used. The galvanometers used for medical purposes are generally wound with several hundreds or even thousands of turns. The resistance thus added to the circuit may be considerable, but as the resistance of the body is itself very high, the effect of the galvanometer resistance in diminishing the current is comparatively slight, and is quiet unimportant as compared with the advantage gained by the multiplying effect of the turns of wire upon the needle. Thus the small currents used in medical treatment are enabled to produce large deflections of the galvanometer needle.

It must not be forgotten that the deflection of the needle of a galvanometer is not in any way a direct measure of the current circulating in it. Galvanometers

are constructed to suit the purposes for which they are intended, and whilst some instruments will give considerable deflections with minute or even infinitesimal currents, others may require currents of comparatively huge magnitude to produce even a slight movement of the needle. On this account it is necessary, before comparing the deflections of one galvanometer with another, to be able to express their deflections in current, and galvanometers may be graduated by comparing them with standard instruments or by the use of a voltameter (see Chap. V.). In buying an instrument, however, it is customary to specify the magnitudes of current which it is proposed to measure with the galvanometer required; the instrument maker is then able to provide a suitable instrument, which has been already graduated to read directly into current.

There are certains features which from the nature of the work they are called upon to perform are common to most galvanometers for medical purposes. The most important is perhaps the method of graduation. These galvanometers are invariably of the fixed coil or "tangent" form, that is to say, the current indicated by any reading, is proportional not to the angle of deflection, but to the trigonometrical tangent of that angle. Hence it is necessary that the circle on which the position of the needle of the galvanometer is read must be graduated, not uniformly, but so that the readings are angles whose tangents increase uniformly.

28. **Electromotive force. Resistance.**—A current is set up in a conductor by electromotive force (see def., § 13), that is to say, the current in any part of a circuit is due to the difference of potential between the ends of that portion of the circuit. This can be measured by means of a suitable electrometer. It is

soon found in working with currents that with different amounts of wire in the circuit different currents are produced by the same electromotive force. There is therefore another factor that determines the magnitude of the current besides the electromotive force, and this factor is called the *resistance* of the circuit.

29. **Resistance of conductors.**—The resistance of a conductor is the inverse of its conductivity, and the conducting qualities of a body may quite well be expressed in terms of its resistance; thus the same idea is conveyed by saying that copper has a high conductivity and that it has a low resistance. As a rule it is more customary and more convenient to speak of the resistances of bodies rather than of their conductivities.

The resistance of a body depends upon the material of which it is made (see "Specific Resistance" below), and upon its length and its thickness. Thus a thick wire has a lower resistance than a thin wire of the same length and material, and a short wire has a lower resistance than a long wire of the same thickness and material.

30. **Specific resistance.**—The electrical resistance of any material is a property peculiar to that material just as its hardness or colour or density is. Most metals are good conductors but they vary greatly among themselves in their electrical conductivity. Silver is the best conductor of electricity and copper comes near to it. Platinum has about six times the resistance of silver, and iron has a resistance slightly greater than that of platinum. As a general rule alloys have a higher resistance than the pure metals; German silver having about fourteen times the resistance of copper. Tables showing the relative conductivity of metals, and

other bodies, are given in textbooks such as S. P. Thompson's *Lessons*.

Tables of resistance are also made with the *specific resistances* of the materials tabulated. Such tables will be found in Everett's *Units and Physical Constants* or in S. Lupton's *Numerical Tables*.

The specific resistance of a material is defined as the resistance of one cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

The resistance is directly proportional to the length of the conductor, and inversely so to its cross-section.

In general the resistance of metals increases with temperature. That of carbon, however, decreases considerably, and in this respect behaves in the same way as electrolytic conductors do (*see below*). The carbon filament of an incandescent lamp has nearly twice the resistance cold that it possesses when hot.

31. **Ohm's Law.**—The law showing the relation between electromotive force, resistance and current was enunciated by Dr. G. S. Ohm and is known as Ohm's law. It is as follows:—*The strength of the current in any circuit or part of a circuit varies directly as the electromotive force in that circuit and inversely as the resistance of the circuit.* This may be expressed in symbols thus:—

$$C = \frac{E}{R}.$$

Where C stands for the current, E for the electromotive force, and R for the resistance. From this formula we obtain in addition $E = CR$, or $R = \frac{E}{C}$. Thus we can calculate either C, E, or R if the values of the other two symbols are known.

32. **Measurement of resistance.**—Ohm's law may be applied to measure the resistance of any given conductor, or rather to compare the resistances of two conductors.

Suppose that the current, passing through the galvanometer can be read off from the deflection of the needle, and it is required to find the value of the resistance R. Join up the resistance R with the galvanometer and battery as in the figure, then since by Ohm's law

$$R = \frac{E}{C}$$

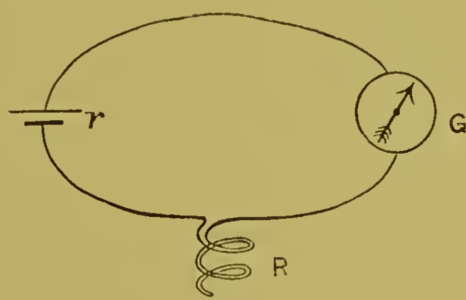


FIG. 5.—Typical circuit.

if E the electromotive force of the battery is known, and C, the value of the current, is read off from the galvanometer, then the total resistance of the circuit can be easily calculated. But this is made up of R the resistance to be measured, and r the resistance of the battery, and g that of the galvanometer. *E.g.*, suppose a Daniell's battery of electromotive force 1·08 volts and resistance ·58 ohm, and a galvanometer whose resistance is 66·3 ohms are used, and the reading of the galvanometer is ·006 ampère (six milliampères) we get

$$R + r + g = \frac{1{\cdot}08}{{\cdot}006} = 180 \text{ ohms},$$

$$\textit{or}\ R = 180 - 66{\cdot}88 = 113{\cdot}12 \text{ ohms}.$$

When exact measurements are required, however, we should not rely on knowing the electromotive force or resistance of the battery with sufficient accuracy for this, so the method must be so modified as to eliminate these. Methods of doing this are described in *Practical Physics* by Glazebrook and Shaw, in the *Textbooks of Science* series, or in *Practical Physics*, vol. ii., by Balfour Stewart and Gee. The method, however, is quite good enough to be useful in certain cases.

By obvious modifications this method may be used for the determination and comparison of the resistances of batteries or galvanometers, or for the determination of the electromotive force of a battery.

33. **Practical units.**—The electro-magnetic units, as in the case of the electrostatic units, are all ultimately defined in terms of the units of mass, length, and time, and as in all electrical and other scientific calculations these are taken to be one gramme, one centimetre and one second respectively, the system of units is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size, *e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. The following system of units derived from these has therefore been adopted for practical use.

Electromotive force.—The practical unit is called the *Volt*. It is a little less than the electromotive force of one Daniell's cell (see § 51).

Resistance.—The practical unit of resistance is called an *Ohm*. The Paris Congress of Electricians in 1884 defined an unit of resistance to be called a "*legal Ohm.*" It is represented by the resistance of a column of pure

mercury at 0° C., of an uniform cross-section of one square millimetre, 106 centimetres long, and weighing 14·4521 grammes, it is slightly less than the true ohm.*

Current.—The current which is given by an electromotive force of one volt acting through a resistance of one ohm is called one *Ampère.*

Quantity.—One ampère flowing for one second carries one *Coulomb* of electricity past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by one ampère in an hour. This is called an *ampère-hour.* It is equal to 3600 coulombs.

Capacity (see § 18).—That capacity which would require one coulomb to charge it to one volt, is called one *Farad.*†

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or sub-multiples of these quantities. Thus, a *megohm* is one million ohms, a *microvolt* is one-millionth of a volt, a *microfarad* one-millionth of a farad, a *milliampère* is one-thousandth of an ampère; this last is the unit of current used in medicine.

34. **Current sheets—current density.**—When a current is led into a large conductor the lines of flow spread out through the conductor. They all of course pass from the anode to the kathode, but spread out into sheets in doing so. The current which passes across unit of sectional area, taken at right angles to the lines of flow at any point, may be called the *density* of the current at that point. In the case of a current in a wire conductor we consider the whole current since

* One thousand million C.G.S. units.

† These names commemorate the labours of Volta, of G. S. Ohm, of André Ampère, of Coulomb, and of Michael Faraday.

the whole sectional area of the wire is taken into account, but with currents flowing in large and heterogeneous conductors like the human body, or even in electrolytes where the density of the current may vary from point to point, it is necessary in order to estimate the effect at any point, to take into consideration the density at that point rather than the whole current. For the physiological effects are largely dependent on the density, that is the ratio of current to sectional area.

35. **Electrolysis.**—In § 22 it was pointed out that during the passage of an electric current through a battery the liquid, or as we then called it the electrolyte, was decomposed, and this decomposition is essential to the passage of the current. Examining into the decomposition more closely, it may be looked on as if it took place as follows:—Owing to the difference of potential set up between the plates, say of zinc and copper, the zinc plate being positive attracts to itself the electronegative portion or *ion* of the electrolyte. In the case of sulphuric acid (H_2SO_4) this is the group of atoms SO_4. At the same time the copper plate being at the lower potential, and therefore negatively charged with regard to the zinc, attracts the electropositive *ion*, *i.e.*, the hydrogen and the state of affairs may be thus represented:—

$$\begin{array}{c} ZnSO_4H_2SO_4H_2SO_4H_2SO_4H_2Cu \\ + - + - + - + - + - \end{array}$$

i.e., a chain of molecules polarized under the influence of the contact difference of potential between copper and zinc. But the *ion* SO_4 is capable of combining with the zinc and so neutralizing its positive charge, and the *ion* H_2 is set free on the copper, thus neutralising the corresponding negative charge there. Immediately of

course the same action recurs owing to the continuously acting contact electromotive force between copper and zinc. In this way a continuous current is kept up, and a continual double procession of the molecules of the electrolyte or ions occurs in the liquid part of the circuit, the electropositive ion passing always towards the copper or positive pole of the battery and the electronegative ion towards the zinc, so that we may regard the copper plate as receiving positive electricity continually from the electrolyte, and passing it on to the circuit. The hydrogen given off at the copper plate does not escape instantaneously, and unless means are taken for removing it, it will set up a back or reverse electromotive force which will greatly reduce the efficient electromotive force of the battery. The battery is then said to be *polarized*. Many methods, chemical and mechanical, have been suggested for overcoming this difficulty, some of which will be described in Chap. III.

If the wires leading from the terminals of a battery are not joined but are led into another electrolyte, an action corresponding to that which takes place in the battery will occur. There will be a tendency to decompose the electrolyte, and if there is sufficient electromotive force in the circuit to overcome the reverse electromotive force of the electrolyte, electro-decomposition or *electrolysis* will take place. Taking the case of water (in practice the water is slightly acidified with sulphuric acid to increase its conductivity) the changes are as follows :—

36. **Anode and kathode.**—Suppose that the poles of the battery are connected to two platinum plates in the water. These plates are called the electrodes. That connected with the copper pole is the one by which the current (considered as a flow of positive

electricity) enters the electrolyte and is called the *Anode*, that connected with the zinc is called the *Kathode*, *i.e.*, the pole by which the current leaves the solution. In the beginning the anode is positive, the kathode negative. The ions in the case of water are hydrogen and oxygen and the former is electropositive and therefore appears at the kathode or negative pole and is called the *kation*, while the oxygen appears at the anode and is called the *anion*. The arrangement of the molecules may be represented thus:—

$$\begin{array}{ccccccc} \text{Kathode} & H_2 & O & H_2 & O & H_2\,O & \text{Anode.} \\ - & + & - & + & - & + \; - & + \end{array}$$

If the electromotive force of the battery is not sufficient to overcome the back electromotive force due to the chemical affinity of the oxygen and hydrogen for each other, matters will rest like this, the electrolytic cell is *polarized*,* the current is stopped, and no appreciable decomposition or electrolysis will take place, but if the electromotive force is sufficient, *i.e.*, about two volts or more, decomposition will proceed, hydrogen being given off at the kathode, and oxygen at the anode.

37. **Laws of electrolysis.**—The laws of electrolysis were discovered by Faraday;† they are as follows:—

a. The amount of chemical action is equal at all parts of a circuit. E.g., if several electrolytic cells, or *voltameters*‡ as they are often called, be arranged in a circuit, the

* It is easy to show that there is an actual reverse electromotive force in the electrolytic cell, by suddenly cutting out the battery and completing the circuit in which the electrolytic cell is included through a galvanometer, which will then indicate a small current in the opposite direction.

† "Experimental Researches," Series V. and VII.

‡ For an account of Voltameters, see Chapter V.

amount of decomposition will be the same in each. If they are water voltameters the same amount of hydrogen will be given off in each, if the electrolyte is copper sulphate solution the same amount of copper will be deposited in each. The same applies in the case of the anions. If some of the voltameters contain water and others contain sulphate of copper solution, the quantities of hydrogen and copper respectively will be proportional to their chemical equivalents.

b. The amount of any ion liberated in any given time is proportional to the strength of the current, and to the chemical equivalent of the ion.

The chemical equivalent for hydrogen is unity, therefore the weight of hydrogen liberated by one ampère running for one second, *i.e.*, by one coulomb of electricity, is the electro-chemical equivalent of hydrogen. For any other ion the product of the weight liberated by one coulomb, multiplied by the chemical equivalent of the ion, is called the electro-chemical equivalent of that ion. The electro-chemical equivalent of silver is very nearly ·001118 grammes per coulomb, and the quantity of silver which one ampère would deposit in an hour is 4·0246 grammes.

38. **Resistance of an electrolyte.**—Just in the same way as the resistance of a metal or other solid conductor is considered, we may speak of the resistance of a liquid or electrolyte. There is more difficulty in measuring this in practice in consequence of the reverse electromotive force of polarization, but if alternate currents be used the specific resistance of an electrolyte may be found, uncomplicated by polarisation effects. The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. The

specific resistance of water is high, and the purer the water the higher it becomes; it would appear, according to the latest experiments, that absolutely pure water if it could be obtained would be a perfect non-conductor. Compared with metals the resistances of solutions are high, thus a salt solution has a specific resistance upwards of four million times greater than that of copper.

39. **Heating effects of a current.**—A voltaic cell may be regarded as an apparatus by means of which the energy of the chemical action between the zinc and the electrolyte (§ 22) can be in part converted into electrical energy and the process may be spoken of as a combustion in which the fuel is the zinc. If a piece of zinc be simply dissolved in sulphuric acid in a test tube the energy liberated is wasted and serves only to warm the contents of the tube, but when the zinc is arranged in a voltaic cell some of the energy can be utilised in the form of an electrical current flowing through the circuit, and this current can be made to do work, or can be again converted into heat in any part of the external circuit of the cell. When an electrical current flows through a circuit its energy is absorbed by the resistance of the circuit and is dissipated in the form of heat, or in other words a wire carrying a current becomes heated by the passage of the current through it. The amount of heat generated depends (1) upon the resistance of the wire, being proportional to the resistance, and (2) upon the magnitude of the current, being proportional to the square of current. Accordingly when it is wished to avoid the production of heat and the consequent loss of energy in a circuit, the conductors should be of low resistance (§ 29); and conversely when the current is to be used for the production of heat, as in the wire loop of a galvano-cautery instrument, or in the filament of an

incandescent lamp, then the resistance of the part of the circuit which is to be heated must be made as high as may be necessary for the circumstances of the case and a comparatively bad conductor must be chosen for that portion.

The energy expended in a conductor may be calculated from the current in the conductor and the electromotive force acting upon it, the figure obtained by multiplying the E.M.F. (in volts) by the current (in ampères) giving the rate of the expenditure of energy in terms of an unit known as a watt.

If E represents the electromotive force and C the current, then the watts W expended in the conductor are expressed by EC.

In any simple conductor the energy expended takes the form of heat. We are consequently able to calculate the rate at which heat is generated in the conductor; and if we know its specific heat and the rate at which it loses heat at its surface, we can calculate the the temperature after the current has passed for any given time.

A watt is not a measure of work done, but of the rate of doing work. To obtain a measure of work done the time during which it goes on must be also considered. Thus one watt for one hour, or shortly, one watt-hour is a measure of work done.

By Ohm's law $E = RC$, and if in the equation $W = EC$ RC be substituted for E, we obtain the formula $W = C^2R$, for the rate of doing work, for losses in a conductor, or for the heating effects of a current traversing a conductor.

The Board of Trade unit in which the energy sold to consumers by the Electric Light Companies is measured is one thousand watt-hours, and costs about sixpence.

This amount of energy can be made up in various ways; for example, taking the ordinary pressure of supply as 100 volts, ten ampères at that pressure for one hour, or one ampère for ten hours, alike represent the amount of energy of one unit. An ordinary incandescent lamp of sixteen candle power requires about sixty watts to keep it at a proper degree of brightness, and on the circuit of 100 volts it takes a current of ·6 of an ampère. Five of these lamps would use 300 watts, and if kept going for five hours the amount of energy absorbed would be fifteen hundred watt-hours, or one Board of Trade unit and a half, costing ninepence, if the price of the unit were sixpence.

40. **Electro-magnetic induction.**—When two distinct circuits are near to each other, currents in one will "induce" currents or, more correctly, electromotive forces in the other.

The induced currents are of momentary duration, and appear only when the inducing current is made to vary, as for example, when it is turned on or turned off. The current induced at the starting of the inducing current is opposite in direction to the inducing current, and the current induced at the break of the inducing current has the same direction as the inducing current. These induced currents were discovered by Faraday, and on that account the induced currents employed in medicine are still known as "Faradic currents" among medical practitioners.

In § 26 it was stated that there is a magnetic field of force about every wire carrying a current, and the effects of electro-magnetic induction just referred to, depend upon the field of force surrounding the wire of the inducing circuit, and generally it may be said that every change of the magnetic condition of the space

round a conducting circuit produces an induced E.M.F. or current in the circuit. Thus the increase or decrease of a current in the inducing circuit, or the approach or withdrawal of the inducing circuit will change the magnetic conditions round the other circuit which may be termed the "secondary" circuit, and will set up a current in it. Also for the same reason the approach or withdrawal of a magnetic pole will set up a current in the secondary circuit during the periods of approach or withdrawal, and since the induced current depends upon the variation of the magnetic field in which the secondary circuit is placed, it matters nothing whether the field is caused to vary by moving a magnet or by making and unmaking a magnet by any means, or by varying a current in the neighbouring circuit.

The production of electric currents by electro-magnetic induction is of enormous practical importance. The commercial developments of electricity rest entirely upon the dynamo-machine, which is purely an apparatus for the generation of electricity by the induction effects of magnetic fields upon moving coils of wire. The importance of the dynamo-machine lies in the fact that it affords a means for the direct conversion of mechanical power into electrical power. It does this so simply, so cheaply, and so efficiently, that the primary battery is becoming obsolete as a source of electrical energy, and survives to day only for a few special purposes, or in remote places.

41. **Induced electromotive force.**—It was stated at the commencement of § 40, that "currents in one circuit will induce currents, or more correctly, electromotive forces" in another. The meaning of the correction is that although the induction of currents implies the induction of electromotive forces, yet electromotive

forces may exist without being able to give rise to currents. It follows from sections 13 and 21 that an electromotive force can only give rise to a current when there is a conducting path for the current. In the case of a circuit acting inductively upon a conductor near it, the latter would be the seat of a current if it formed part of a closed conducting circuit; but if it did not do so it would be the seat of an electromotive force only, as its circumstances would be against the production of a current in it.

In order to arrive at the magnitude of induced currents we must consider that by Ohm's law (§ 31) this depends upon two quantities, the electromotive force and the resistance of the wire. This latter is constant, since it depends only on the wire; the electromotive force alone varies. Its direction has been already considered, its magnitude is determined by the following law:—The total induced electromotive force in any closed circuit is proportional to the rate of change of the number of magnetic lines of force through the space enclosed by the circuit. But the number of lines of force, or in other words, the strength of the magnetic field produced by a current in a circuit is proportional to the current in that circuit. Hence the law may run "*the induced electromotive force in any closed secondary circuit is proportional to the rate of change of current in the primary circuit.*"

42. **Self-induction.**—When a current is sent through a circuit, the magnetic field which is set up round the conductor reacts upon the conductor itself, just as we have seen it do upon a neighbouring circuit, and thus at the moment of completing a circuit the rise of current in it to its proper value is retarded by an induced electromotive force of opposite sign in the wire itself:

while when the circuit is broken there is a momentary reinforcement of the current by an induced electromotive force of the same sign as that existing in the wire. This action of an increasing or decreasing current upon its own circuit is spoken of as an action of self-induction, and the reinforcement of the current at the break produced in this way can be amplified and made use of as will be seen later in the account of medical induction coils (Chap. V.).

CHAPTER III.

Batteries.

Essentials of a good battery. Electromotive force of cells. Capacity of cells. Polarization. The Smee, Bichromate, Daniell, Grove and Bunsen batteries. Leclanché battery. Dry batteries. Chloride of silver battery. Oxide of copper battery. Sulphate of mercury battery. Stöhrer's battery. Accumulators. Table of batteries. Choice of a battery. Care of a battery.

43. **Essentials of a good battery.**—Numerous modifications of Volta's original cell have been from time to time proposed with the object of improving it, so as to obtain as high an electromotive force as possible, to diminish the internal resistance, and to secure constancy of action. For medical work the most important point of all is to find a cell which will remain for a long time in good order without attention, and in which no wasteful chemical action goes on when the battery is not in use. On this account the Leclanché battery (§ 53) or some modification of it has been almost universally adopted as the cell *par excellence* for medical purposes.

44. **Electromotive force of cells.**—The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 21, it depends almost entirely on the contact electromotive force between dissimilar substances. Tables are found in electrical textbooks of metals arranged in order, the most electro-positive at the head of the table, the most electro-

negative at the foot. An abbreviation of such a table*
is the following:—

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Electronegative.

This order is given for the elements in contact in presence of dilute acid; under other circumstances the order is liable to some alteration.

It follows that the battery with the greatest electromotive force would be one, the poles of which consisted of the two materials at the extreme ends of the table, and most of the improvements in batteries made with the object of increasing the electromotive force have been by substituting metals further down the list for the copper plate of Volta's cell. Thus in Smee's cell we find a platinized silver plate is used for the positive pole, in Grove's battery a platinum plate, while in Bunsen's carbon is used. Until, therefore, it becomes practicable to use magnesium or sodium instead of zinc, we can hardly expect to obtain primary batteries of higher electromotive force than those in which zinc and carbon poles are used. The best of these batteries, when working properly, have an electromotive force of something under two volts. That of a Bunsen's cell is from 1·8 to 1·9 volts.

* Miller's "Chemistry."

As will be seen in the description of secondary batteries a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been suggested under the name of the zinc-lithanode battery, and it is said to have an electromotive force of 2·5 volts per cell.

If several cells be coupled together in series, that is to say, with the negative pole of the first joined to the positive pole of the second, and so on, the electromotive force of the combination measured from the positive pole of the first to the negative of the last cell, will be equal to the sum of the electromotive forces of the cells taken separately, thus, when high electromotive forces are required, the arrangement of a sufficient number of cells in series provides a means of obtaining it. If ten cells of an electromotive force of 1·5 volts apiece be arranged in series the electromotive force of the whole battery will be fifteen volts. In medical treatment an electromotive force of 30 or 40 volts is commonly required; and a medical battery is therefore provided with a suitable number of cells connected together in series to give such a voltage.

45. **Internal resistance.**—This is determined by the nature of the fluid in the cell, by the distance between the plates, and by the area of the plates. The internal resistance is low if the plates be large and close together, and high if the plates be far apart or small. If the whole circuit of a cell be considered, and divided into two parts, the external circuit in the wire, and the internal inside the cell itself, then a comparison of the resistances of the two parts will show what proportion of the total electrical energy of the battery is available for use in the external circuit, and what proportion is

expended uselessly inside the cell itself; for example, in the case of a cell having an electromotive force of 1·5 volts, with an internal resistance of three ohms, and connected through an external resistance of six ohms, the energy expended in the outside circuit will be two-thirds, and that expended inside the cell will be one-third of the total. Of the total difference of potential, one-third (or ·5 volt) will be used up in the cell, and the remaining two-thirds (or 1 volt) will represent the available electromotive force of the cell for doing work in the outside circuit.

If the external resistance be 997 ohms and the electromotive force and internal resistance be as before, then the available electromotive force acting upon the external circuit will be very nearly the same as the full voltage of the cell; actually it will be ·997 of 1·5 volts.

Thus one sees that in certain cases the internal resistance of a cell is an important factor in determining its value as a source of current, while in other cases it is insignificant. In working with the large resistances of the human body the internal resistance of the cells composing the battery is an unimportant matter, as it forms a small fraction of the total resistance of the circuit, and the loss of electromotive force inside the cells is therefore a small fraction also.

In working with low external resistances, as in cautery work, and to a less degree in the illumination of parts of the body by incandescent lamps, the internal resistance of the cells becomes important, and special forms of cell with low internal resistances are designed for such work.

46. **Arrangement of cells.**—The arrangement of cells in series has already been alluded to; and is re-

presented in figure 6. Cells may also be arranged in parallel (fig. 7), that is to say two or more cells may have their positive poles connected together to form one pole of the battery, and their negative poles in like manner to form the negative pole. When cells are connected in series the electromotive force of the battery is the sum of the electromotive forces of the cells composing it; the internal resistance of the battery is also the sum of the internal resistances of the cells. When similar cells are connected in parallel the electromotive force of the combination is no more than the electromotive force of one of its components; but its internal

FIG. 6.—Six cells arranged in series.

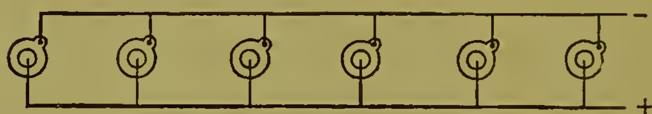


FIG. 7.—Six cells arranged in parallel.

resistance is diminished in proportion to the number of cells coupled together. With six cells in parallel the internal resistance is one-sixth of that of one cell. It is sometimes useful to couple up the cells which are at hand in the best manner for obtaining the desired result, as the following example will show:—

Suppose the resistance of a cautery is ·1 ohm, and the cells to hand are ten bichromate cells of 1·6 volts each and ·5 ohm internal resistance, and suppose that the cautery requires eight ampères to heat it. If the cells are coupled up in series we shall indeed get an electromotive force of sixteen volts acting through a resistance of 5·1 ohms, and this will give a current of 3 ampères,

but if they are coupled in parallel, the battery resistance will be only ·05 ohm, and the total resistance will be but ·15 ohm in the whole circuit. True the electromotive force will be only 1·6 volts, but by Ohm's law the current in this case will be 10·6 ampères. In the former case the cautery would not be heated, in the latter we should have enough current and to spare. *Vice versâ*, it is futile to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1000 ohms, compared with which the internal resistance of thirty Leclanché cells in series is small.

47. **Polarization.**—Much attention and ingenuity have been concentrated upon securing constancy of current and absence of polarization in batteries. This is easily seen to be an important matter, for nearly all batteries undergo a rapid fall of electromotive force when any large current is taken from them. Thus, for example, a form of cell recently put upon the market had an electromotive force of 1·508 volts on open circuit, but after being short circuited through a wire of low resistance for fifteen minutes the electromotive force had fallen to ·433 volts. Polarization of a cell is mostly caused by alterations in the surfaces of the plates of the cell, and chiefly by the condensation of hydrogen on the inactive plate which sets up a reverse electromotive force, and so reduces the available electromotive force of the cell, at the same time reducing the available area of the plates, and thereby increasing the internal resistance of the cell (see § 45).

There are other causes which tend to produce a falling off in the current that a cell can give, particularly the exhaustion of the exciting fluid, if it be not renewed from time to time.

To prevent polarization it is necessary to take some measures that will check or disperse the accumulation of hydrogen on the positive pole.

48. **Depolarizers.** — Depolarizing methods can be conveniently grouped under three heads:—(*a*). Mechanical methods. (*b*). Liquid depolarizers. (*c*). Solid depolarizers.

In Smee's battery the surface of the silver plate is roughened by being platinized, *i.e.*, covered with finely divided platinum, the effect of which is that the bubbles of hydrogen are able to form and escape more easily. In Walker's modification of this battery (see § 58, Stöhrer's battery), the rough surface of the carbon plate used plays the same part, but it probably acts chemically also by causing oxidation of the hydrogen in the same way that the carbon of charcoal filters causes the oxidation of the organic matter of impure water. Another mechanical method of hindering polarization is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods, however, are so efficacious as the use of chemical means, that is to say the use of some oxidising agent in the cell whereby the hydrogen is consumed, instead of being deposited on the positive plate. The simplest method of doing this is to add to the exciting liquid some powerful agent that will oxidise the hydrogen as fast as it is liberated. Thus chromic acid is used in the "bichromate" battery (§ 50) invented by Poggendorf. The chemical action of the depolarizer upon the hydrogen reinforces the electromotive force of the couple. Another liquid depolarizer that is much used is strong nitric acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate by the use of a semi-permeable porous partition or porous pot, and the

battery then becomes a two-fluid battery. In figure 8 the arrangement of a two-fluid battery is shown ; V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

There are several solid depolarizers in use, the one best known being peroxide of manganese, which is used in the Leclanché cell, and in several of the "dry" cells. Oxide of copper is also used. Fused chloride of silver is the depolarizer in a battery known as the chloride of silver cell.

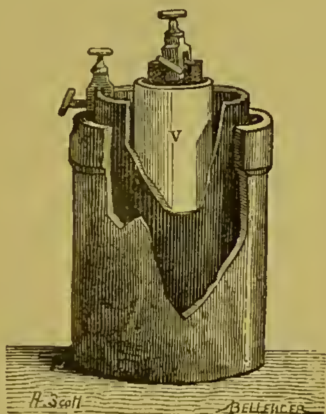


FIG. 8.—Two-fluid cell.

49. **Smee's battery.**—This battery is of interest, as representing the simplest advance on the copper-zinc couple of Volta ; it was invented in 1840. In its usual form it is made of two flat plates of zinc, separated from one another above by a block of wood which supports a platinised silver plate between the zincs. The exciting liquid is dilute sulphuric acid 1 to 10. In spite of the roughened surface of the silver plate the battery soon polarizes, and its available electromotive force is not much more than ·5 volt.

50. **Bichromate battery.**—This is a favourite form of cell where large currents are required occasionally. Its constancy, however, is by no means perfect. Its plates are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. A part of the sulphuric acid sets free chromic acid, and this being a very powerful oxidising agent, combines with the hydrogen liberated on the carbon plate by the action of the battery, and is reduced to chromous oxide; this combines with a further quantity of sulphuric acid to form chromous sulphate, which remains in solution, giving the liquid a dark green colour. After a time, crystals of chrome alum (potassium chromium sulphate) will be deposited, which are hard and difficult to dissolve. Sodium bichromate has been strongly recommended instead of the potassium salt, as the sodium chrome alum is very much more soluble; the sodium salt also contains, weight for weight, more chromic acid than the potassium salt. A suitable formula for preparing the exciting liquid is the following:—Potassium bichromate or sodium bichromate, 6¼ ounces; water, 35 ounces; sulphuric acid, 6 ounces.

When the battery begins to show signs of being exhausted an additional ounce of acid per quart may be added.

The zincs of this battery must always be removed from solution immediately after use, and in fact should be well washed and frequently re-amalgamated, if the battery is to give the best effect. Bichromate cells are frequently fitted up in portable induction coil sets. Forms of bichromate battery are also known to medical men under the name of Stöhrer's and Reiniger's batteries; but they are not to be recommended, as

they require much attention and cleaning. Stöhrer's battery will be more fully described in § 58. The outward form of the bichromate battery varies very much. A very familiar shape is that of a bottle (fig. 9). The plates are suspended from a vulcanite lid carrying binding screws, and the zinc plate can be drawn up out of the liquid into the neck of the bottle when the battery is not in use.

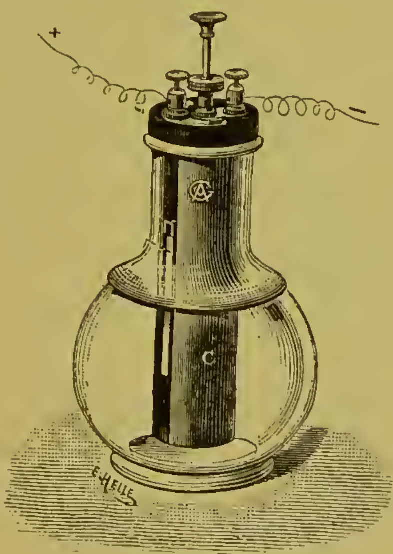


FIG. 9.—Bichromate battery.

51. **Daniell's battery.**—The oldest and most constant form of two-fluid battery is that known as Daniell's cell. So constant is this cell that it has been proposed and frequently used as a standard of electromotive force. For rough purposes we may take the electromotive force of a Daniell's cell at one volt. A Daniell's cell consists of a copper plate placed in a solution of sulphate of copper, which is kept saturated by having a few crystals of copper sulphate on a shelf

near the top of the liquid; separated by a porous partition is a zinc plate in solution of sulphate of zinc slightly acidified with sulphuric acid. Frequently the copper plate is made also to serve as the containing vessel. The porous partition while it prevents the mixing of the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions then are as follows:—Zinc is dissolved at the zinc plate and hydrogen would be set free at the division between the two liquids but for the presence of the copper sulphate solution which being itself an electrolyte is decomposed into sulphuric acid, which passes inwards from the porous partition, and copper which is deposited at the positive pole. Since this latter is already of copper there is no tendency to polarization here at all, and any falling off in the electromotive force of the cell is due to bad amalgamation or some other fault at the zinc plate. Daniell's batteries, are sometimes arranged as "gravitation batteries," the porous division being abolished and the lighter liquid with the zinc plate standing above the heavier sulphate of copper solution. Daniell's cells might be useful in medical practice for charging accumulators.

52. **Groves' and Bunsen's batteries.**—These have for their depolarizer strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the positive pole is contained in a porous pot filled with strong nitric acid, and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid (fig. 8). The fumes and the corrosiveness of nitric acid form the greatest objection to the use of this battery. It must be taken to pieces and cleaned every time it is used. If it can be set up in a draught cupboard or

outhouse it is useful for recharging accumulator cells, but the process is troublesome.

53. **The Leclanché battery.**—The cell most universally used for medical work is the Leclanché battery (fig. 10), the exciting solution in which is a saturated solution of ammonium chloride (sal ammoniac). The negative pole is a zinc rod and the positive pole a carbon plate or rod. This is surrounded by the depolariser, manganese dioxide, which is able slowly to oxidise any

FIG. 10.—Leclanché cell.

hydrogen evolved by the action of the cell. In the older forms of Leclanché cell the carbon pole was packed tightly in a porous pot with fragments of carbon and granular manganese dioxide. Another form of cell has no porous pot, and thus its internal resistance is somewhat reduced, and the carbon has attached to it a conglomerate formed of manganese dioxide and carbon pressed into blocks. This form is called the agglomerate type.

When the circuit is open there should be practically no action between the solution and the zinc; but when the circuit is closed the zinc is dissolved, forming a double chloride of ammonium and zinc, and an oxy-chloride of zinc, while ammonia and hydrogen are evolved at the carbon pole. If only a small current is taken from these cells their action is fairly constant, but if much current is used the oxidising action of the manganese dioxide is unable to keep pace with the evolution of hydrogen and the cell becomes polarized, though it recovers completely if left for some hours on open circuit. The electromotive force of a new Leclanché cell is about 1·5 volts. The advantages of the battery are that it possesses great powers of recovery, has no appreciable local action and may consequently be left for months at a time without attention, and has a fairly high electromotive force. Against these we must set the fact that its electromotive force runs down rapidly when it is called on to produce a current of any magnitude.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the way that Leclanché batteries can, for in all of them the local action would soon destroy the zinc if it were not removed from the acid as soon as the battery was done with, and on that account alone acid cells are not suitable for medical purposes, since they require too much attention. Medical batteries must allow of being carried to patients' houses when necessary, and cells with acid liquids in them are most awkward; accordingly, except for special purposes, the Leclanché cell is almost universally employed, for in it the zinc can be left always in position without waste from local action, and the cell can be closed in with pitch or

cement, to prevent any escape of fluid from within; these conveniences are purchased at the cost of a high internal resistance and of a tendency to polarization, but for most medical work these objections are not very serious, because the amount of current required in most cases is only a few thousandths of an ampère (5 to 50 milliampères). Even when the portability of the battery is not important the Leclanché element is still preferred, for once installed in a cellar or a cupboard, it can be left alone without attention for years, and if large cells can be used instead of small ones, the internal resistance can be reduced, while the capacity of the cell for doing work can be increased. The Leclanché cell then is the one most commonly used for medical purposes, and its management, mode of action, defects and good qualities should all be mastered by those who intend to work at the subject of medical electricity.

Numberless modifications of this cell have been put upon the market at different times, but these have differed from the original type, mainly in such details of construction as shape of cell, omission of porous pot, and shape of plates. We shall further consider one of the modifications in treating of "dry" batteries (§ 54).

To preserve Leclanché cells in good order they must receive a little attention from time to time about once in six months or so. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened they should be scraped and amalgamated, and the liquid can be renewed by adding solution of sal ammoniac to replace any loss from evaporation. The cells must not be filled to more than two-thirds of their capacity. If the amount of work done by the battery has been large and the solution has

become milky, it had better be withdrawn by means of a syringe or a syphon, and fresh solution put into its place. The proportion of six ounces of sal ammoniac to a pint of water makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline or hot paraffin wax to prevent *creeping* of the salts. This is the formation of crusts of the sal ammoniac around the top of the cell, it is harmful because it may lead to corrosion of connecting wires, so breaking the circuit.

When hard crystals form in masses at the bottom of the cell and round the zincs it is time to take down the battery and to set it up afresh. These crystals are a double chloride of zinc and ammonium, and are insoluble in water. When they have formed in the outer vessel, they have probably formed in the porous pot as well, and their presence there is not desirable, because they increase the internal resistance of the cell and block up the interstices of the carbon and manganese dioxide. If there is reason to think that the cells are worn out, the porous pots may be recharged with manganese dioxide and broken carbon, which can be bought ready mixed, or better still they can be replaced by new ones. The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition; one can do little beyond emptying out the liquid with a fine syringe and putting in fresh sal ammoniac solution in the same way from time to time, and to do even so much as this is a tiresome operation. If the cells when new are charged with pure zinc chloride, 1 in 6, instead of with sal ammoniac, they will last a long time without the formation of the hard crystals, and can be recharged with fresh zinc chloride solution, slightly acidified with

hydrochloric acid. Unfortunately, however, these small cells as sent from the makers, have already inside them a charge of sal ammoniac, requiring only the addition of water to set them in action. It is of no use to charge these with the zinc chloride. The most expensive part of the small medical Leclanché cell is its vulcanite case. In the dry cell this is dispensed with and the latter are therefore cheaper.

54. **Dry batteries.**—These are in many ways exceedingly convenient. They are sealed cells of the

FIG. 11.—Hellesen's dry cell.

Leclanché type. They will work in any position and require no special attention whatever, but it must be remembered that all sealed forms of cell have a capacity for work strictly limited by the original charge of chemicals, and cannot be restored to action when run down by the addition of fresh exciting liquid. In most of them the zinc plate is shaped like a canister and forms the containing vessel of the cell, it is packed with a paste of exciting material, and inside this is the

carbon and manganese dioxide. Cells of this type can be obtained from the General Electric Co. (the E. C. C. cell), and from Messrs. Siemens Bros. (the Obach cell and the Hellesen cell).

The "Hellesen's patent dry cell" works very satisfactorily (fig. 11). Like the other dry cells it is a modified Leclanché battery as the poles consist of zinc and carbon and the exciting salt is sal ammoniac mixed with quicklime, while the depolarizer is manganese dioxide. They are made in several sizes, the smallest size for portable medical batteries, weighs only eight ounces, and is a very good cell. It will last for a year and a half or two years with proper care, and after that time must be rejected. They cost eighteenpence apiece. The larger sizes are very good for working induction coils. A newer cell by the same firm known as Obach's dry cell is also recommended as a good dry cell.

55. **Chloride of silver cell.**—The chloride of silver battery was invented in 1868 by Warren de la Rue and Hugo Müller, and modified and improved by Skrivanoff in 1883. It possesses some good qualities, but it is a rather expensive cell to buy. Unfortunately the silver chloride passes into solution after a time, and is reduced to metallic silver on the surface of the zinc. Local action then sets in, and the cell rapidly deteriorates. An American firm claims to have overcome these difficulties and now manufacture a very neat and convenient form of this cell.

56. **Lalande oxide of copper cell.**—This cell as modified by Edison consists of plates of zinc and copper; oxide of copper compressed upon the copper plate acts as a depolarizer, caustic soda is the exciting fluid. The cells are said to be very constant, and can furnish large currents. There is little or no local

action. Their electromotive force is low, ·8 of a volt, and they are not suitable for a portable battery (fig. 12), but might have a use in remote places for cautery work or for charging accumulators. They can be had from the General Electric Co. in several sizes.

57. **The sulphate of mercury battery.**—A battery that has been used for medical purposes, especially in the pocket induction coils sold by M. Gaiffe, of Paris, consists of plates of zinc and carbon in a solution of

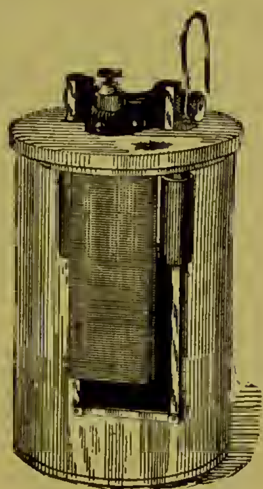


FIG. 12.—Edison-Lalande cell.

sulphate of mercury. In the apparatus mentioned above two small cells are generally supplied in the form of little ebonite trays with carbon plates on which is placed a small quantity of the commercial sulphate of mercury, and a little water; the zinc plates are then laid on this and are kept from contact with the carbon by three vulcanite studs. The electromotive force is about 1·45 volts per cell.

Latimer Clark's standard cell is a form of sulphate of

mercury cell, which is used in laboratory experiments, but it requires the utmost delicacy in management, and is used solely as a standard for the comparison of electromotive forces; its electromotive force is 1·434 volts at 15° C.

58. **Stöhrer's battery.**—This battery, once largely used in medical work, is a modified form of bichromate

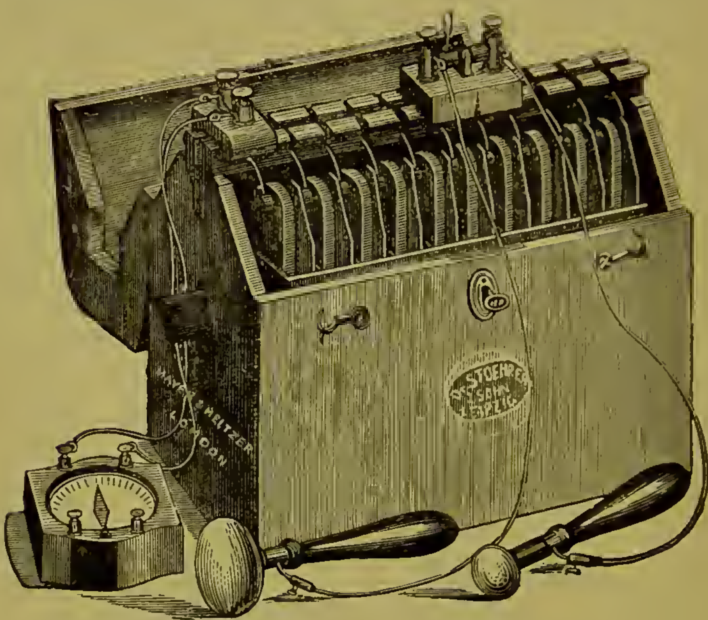


FIG. 13.—Stöhrer's battery.

battery. The elements, zinc and carbon, are arranged in a double row on a wooden bar, so that a double row of glass or earthenware cells containing the exciting fluid can be raised up to them in such a manner that the correct pairs of plates dip into each cell (see fig. 13).

The battery may be made up to contain 20, 30, 40, or even 60 cells, these form a double row in a strong oak

box, and a beam of wood with a deep channel cut in it extends from end to end of the box in the middle line; the pairs of plates are all suspended from this beam by stout brass rods, which convey the current from the cells to a travelling collector.

The collector which slides in the groove of the beam carries two flat brass springs which make connection with the brass rods from which the pairs of plates hang. From the springs the current is led through a commutator to a pair of binding screws, and from these the wires may be led to the place where the current is required. It may be noticed that Stöhrer's battery was originally designed for use with dilute acid only, as in Walker's modification of Smee's cell, but the addition of the chromic acid depolarizer obviously improves its action.

The battery is not portable owing to the quantity of corrosive liquid in the cells, and it is very troublesome and difficult to keep it clean, and its zinc plates amalgamated. It is therefore becoming obsolete.

59.—**Accumulators or secondary batteries.**—A so-called *secondary battery* has the property that when it is run down and exhausted it may be renewed by driving an electric current into it and thus setting up an electrolysis that brings the plates and the electrolyte back to their former state, while in the *primary batteries* it is necessary to renew these. There is no more actual storage of electricity in these batteries than in a primary battery. Either may be looked upon as a store of energy, and in both the energy stored is energy of chemical action. Secondary batteries are classified into two types, in both of which the plates are of lead. The older cell of the Planté type has porous lead plates, placed in dilute sulphuric acid as the electrolyte; these

cells then require "forming," that is, a current is passed through them for a certain time, and they are then allowed to discharge themselves through a resistance, they are then charged in the opposite direction and allowed to discharge again, and this process is repeated several times. The object of this "forming" process is

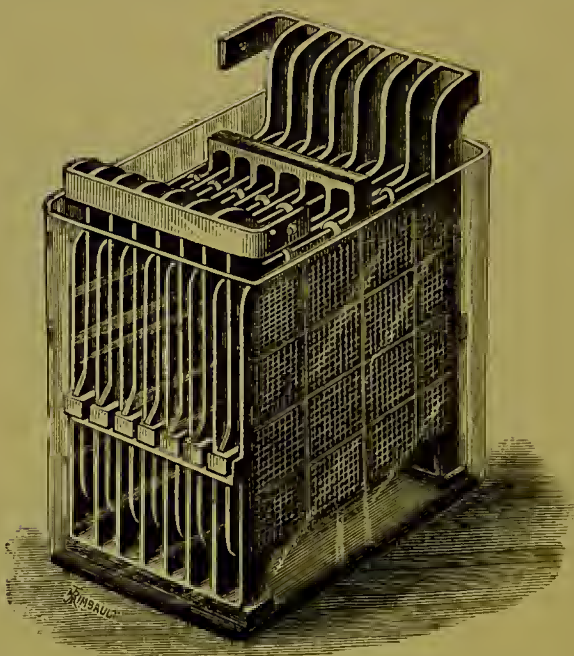


Fig. 14.—Accumulator in glass vessel, showing arrangement of plates.

to increase their capacity by the production of a thick layer of lead peroxide upon the plate which is positive, and of spongy metallic lead upon the negative. In the other type of cell, the plates are perforated grids of lead, and the holes in the positive plates are filled with a paste made of red lead or peroxide of lead and dilute

sulphuric acid, which sets fairly hard in them. Those in the negative plate are filled with a paste of litharge and sulphuric acid. The plates, formed into "sections" of positive and negative plates arranged alternately, are placed in the cells, and these are filled up with dilute sulphuric acid, of sp. gr. 1·170, and they are ready for the first process of charging. This is called "forming" the cells, and consists in charging them for a very long period, say about thirty hours. When a cell has just been charged it will be found to have an electromotive force of nearly 2·5 volts, but the working voltage is 2 volts. When the cells are discharging, the electromotive force is maintained till about 75 per cent. of the ampère hours that the cell will give has been done, and then the electromotive force falls quickly.

It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts or 1·8 at the lowest that cell should at once be recharged. If it is not attended to the cell becomes injured, and sulphates of lead are liable to form which increase its internal resistance and decrease its storage capacity, and the grids are liable to buckle and lose their paste.

It is not easy to give much idea of the storage capacity of these cells, but a well designed one should be capable of giving about 5 to 7 ampère hours per pound of lead.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them unless a very large number are coupled up in series, since the current that may be taken out of the cell is limited by other considerations. It is this low internal resistance which makes them so useful for cautery purposes, where large currents are needed. As the paste is liable to

leave the plates if too large a current be taken from a cell, it follows that the practice of flashing the cells to see if they are in working order, viz., connecting their poles through a short piece of copper wire for an instant is very injurious to the life of a cell for this treatment produces a rush of current of considerable magnitude, and it tends to loosen the paste and set up deleterious sulphating. Accumulator cells must never be allowed to fully discharge themselves, they should be tested from time to time with a voltmeter, and as soon as the electromotive force of a cell sinks to below 2 volts it must be recharged.

The difficulties found in working with accumulators of the type having "pasted" plates has caused some makers to return to the original type of accumulator as invented by Planté, where no pastes of the oxides of lead are used.

The Lithanode Cell* is another form of secondary cell which works well, and is made in several different sizes and in portable sets some of which are admirably adapted for medical purposes, particularly for lighting small incandescent lamps. These cells are light and compact, and the company undertake all arrangements for recharging and maintenance at a small cost. They make small accumulator cells weighing only four ounces, which might prove useful for medical batteries wherever the recharging can be done without trouble (fig. 16), and also smaller cells whose weight is only two ounces and a half. In the lithanode cells the positive plates consist of slabs of a very dense lead peroxide compound enclosed in a metallic framework, and they are free from some of the faults common to the "pasted" plates.

* The Lithanode Electric Storage Co., Harvey Buildings, 427A Strand, W.C.

60. **Table of batteries.**—The appended table of batteries may be of service. The internal resistance, though a most important factor in calculations as to the discharging rate of a cell, varies with the size of the

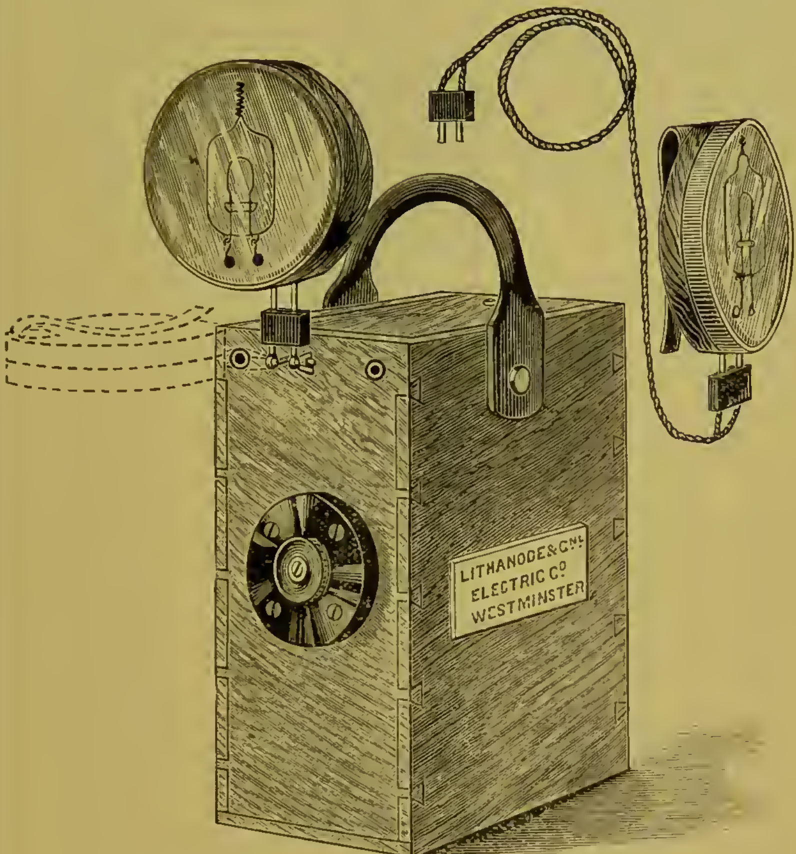


FIG. 15.—Five-cell lithanode cell with detachable lamp.

cell. An internal resistance which at all nearly approaches one ohm makes a battery useless for cautery purposes.

The resistance of the bichromate cell depends upon

its size and make, generally speaking in the types manufactured for cautery heating and for lighting it is made as low as possible and is about ·15 ohm. The

FIG. 16.—Lithanode testing cell.

resistance of Daniell's cell depends on its size and the density of the porous pot used, and varies from about ·3 to 2 ohms. A quart Grove or Bunsen cell has a resistance of about ·15 ohm. The Edison-Lalande

battery is also specially constructed for cautery work, and in the larger forms the internal resistance may be brought as low as ·05 ohm. That of a Leclanché cell varies from about ·5 in the largest sizes to two, three, or five ohms in the smallest ones. The internal resistance of the various dry cells is given by the makers as from ·1 to 1 ohm according to size. The secondary batteries all have a very low internal resistance indeed, according to the number and size of the plates.

TABLE OF BATTERIES.

NAME.	ACTIVE PLATE.	EXCITANT.	DEPOLARIZER.	PASSIVE PLATE.	APPROXIMATE ELECTRO-MOTIVE FORCE, VOLTS.
1. Bichromate. .	Zinc	Dilute sulphuric acid, 1-8	Chromic acid	Carbon	1·9
2. Daniell . . .	,,	Zinc sulphate or dilute sulphuric acid, 1-12	Copper sulphate	Copper	1·079
3. Bunsen . . .	,,	Dilute sulphuric acid	Strong nitric acid	Carbon	1·9
4. Edison-Lalande		Potassium hydrate 40 per cent.	Cupric oxide	Copper	·8
5. Leclanché . .	,,	Ammonium chloride solution, saturated.	Manganese dioxide	Carbon	1·48
6 Hellesen . . .	,,	Ammonium chloride and lime	,,	,,	1·5
7. Secondary battery	Lead	Dilute sulphuric acid, sp. gr. 1·170	Lead peroxide	Lead	2

Cells which have a low internal resistance are much more easily run down by any accidental short circuiting than those with a high resistance. If an accumulator cell with an internal resistance of ·05 ohm be short

circuited, it may discharge at a rate of 40 ampères, which will very quickly exhaust it, and most likely damage it seriously as well.

61. **On the choice of a medical battery.**—In choosing a battery for medical purposes the essentials are to have one which is efficient and does not require frequent attention. For a complete outfit two separate batteries are required, one for diagnosis and treatment, and one for lamps and cauteries. In many cases it is necessary to carry a battery to the houses of patients, therefore, portability must not be lost sight of. Medical batteries are sold by electrical instrument makers consisting of from 25 to 40 cells arranged in a case and fitted with commutator, current collector, galvanometer and induction coil. These are quite suitable for testing the reactions of nerve and muscle, for general medical treatment and for electrolysis. The cells used are usually either small Leclanché or "dry" cells. Owing to their smallness their capacity is not large and they cannot long give out large currents without becoming exhausted. With proper care they may be counted upon for a year or two for all ordinary purposes of testing and treatment, including occasional use for the electrolysis of nævi, which demands fairly large currents, and then will require recharging or renewal. The best plan perhaps is to use small dry cells, and renew them altogether when exhausted. The medical Leclanché cell costs more on account of its ebonite case, these if returned can be allowed for, but it is better not to be troubled with them. The dry cells cost only about eighteenpence per cell. For working the induction coil in portable medical batteries two cells of larger size are fitted; these run down more rapidly than the others and require renewal more frequently. Catalogues

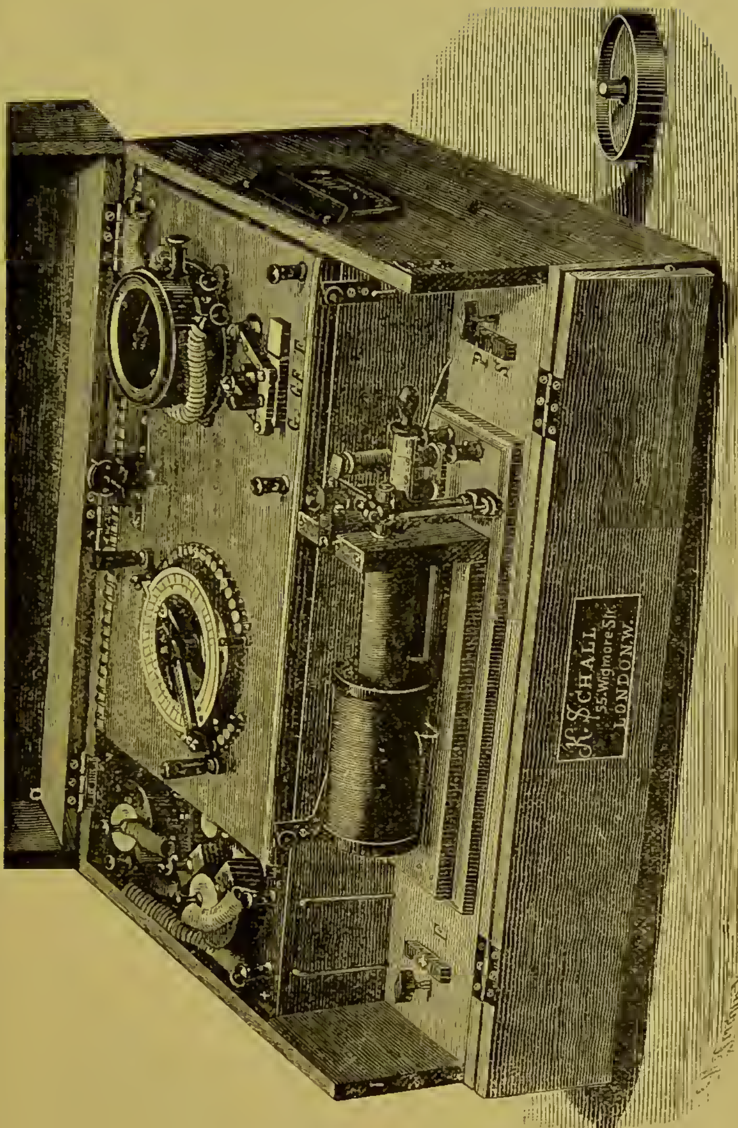


FIG. 17.—Schall's combined battery.

may be consulted by those wishing to purchase anything of the sort. The details of the fittings of these

batteries vary with the different makers, but instructions for use are usually supplied with the instruments. For heating cauteries and for electric light instruments, a four cell accumulator arranged with a switch to connect the cells into two pairs in parallel, or into four cells in series, and provided with an adjustable resist-

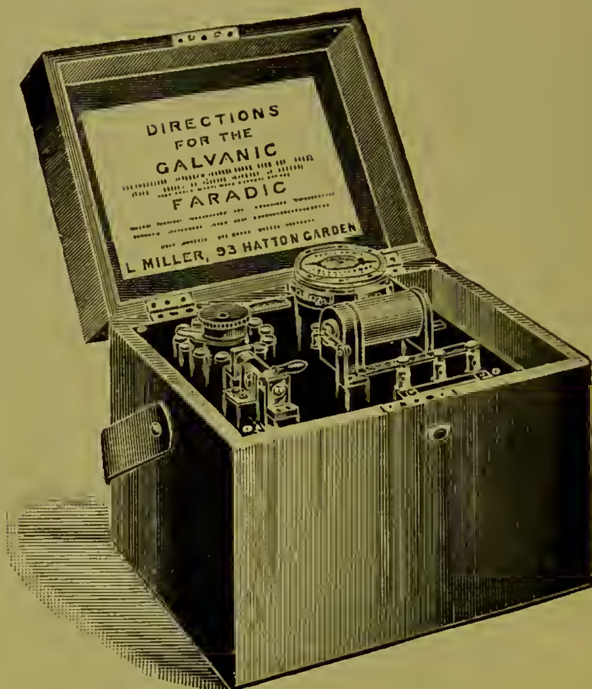


FIG. 18.—Combined medical battery.*

ance is the best battery, unless the recharging is an obstacle. In that case a four cell bichromate battery of large size, with proper connections, will serve the same purpose.† For further details of lamp and cautery

* L. Miller, 93 Hatton Garden, W.C.
† K. Schall, 55 Wigmore Street, price £6.

outfits see Chapter XV. There is no need to have a fixed installation in the consulting room as well as a portable combined battery, for the latter will serve at home as well as in the houses of patients, and as all battery cells tend to deteriorate in time whether they are used or not, there is twice the cost of maintenance with two batteries that there is with one. Naturally it is convenient sometimes to have a fixed installation of large cells at home, as well as a portable set; but it is more economical and less troublesome to have few batteries.

An exception may be made in favour of a separate induction coil. The coil is more often required for purposes of treatment than a constant battery; and it is a convenience to have a light-weight induction coil, for then the labour of transporting a heavy combined battery will sometimes be saved.

It may be useful here to mention the best types of cell for the various purposes to which they may be put by medical men :—*For general medical purposes* of testing and treatment, 25 to 30 dry cells of small size. *For working induction coils*, one or two dry cells of larger size. *For medical lamp instruments*, four or five cells of a secondary battery, or six large bichromate cells. *For cautery purposes*, two secondary cells, or large bichromate, or Edison-Lalande cells. *For recharging accumulators*, Bunsen or Daniell cells; for method of procedure see end of next paragraph.

62. **Care of batteries.**—The trouble of keeping batteries in order is commonly put forward as an excuse for neglecting electricity in medical practice. It is important in buying a battery to choose one which will remain in good order without much attention. On this account acid cells are to be avoided as much as pos-

sible. Small dry cells should always be preferred for portable batteries. In country places some large bichromate cells may be a necessary evil for cautery and lamp work, but wherever dynamo currents can be had for charging purposes an accumulator is better.

To keep a bichromate cell in good order it must be attended to. If its action fails and the liquid is found to be dark green in colour it must be renewed, if it is still orange a dose of strong sulphuric acid will restore it for a time. The cell must be taken down occasionally, the carbon plates soaked in water and brushed with an old tooth brush, and the zincs must be also washed clean and amalgamated; to do this they should be scraped fairly smooth and wetted with dilute acid and then some mercury should be well rubbed into them with a piece of old leather or wood. The surface when properly amalgmated looks as bright as silver and should appear to be wetted by the mercury at every point.

The zincs must never be left in the chromic solution when not in use, as it attacks zinc with great facility.

To charge an accumulator from a primary battery, the latter must have an electromotive force greater than that of the cells to be charged. For a two-celled accumulator, five Daniell cells, three bichromate, or Bunsen cells, or seven Edison-Lalande cells are required. The charging cells should be large, the process is as follows:—The primary battery having been freshly charged, coupled in series, § 46, and tested to see that it is in good order, it must be attached to the accumulator, positive pole to positive pole, and negative to negative. Current will then pass to the accumulator from the battery so long as its electromotive force keeps

up above that of the secondary cells. The current will slowly diminish as the primary cells run down; when the electromotive forces of the primary and secondary cells are in equilibrium no current passes in either direction; if the primary cells run down more the current will set in the other direction and the accumulator may discharge itself through them and thus defeat the object of the charging operation.

The operation must accordingly be watched and stopped before the charging current has fallen to zero. A suitable ammeter (Chap. V.) will show the magnitude and direction of the current which is passing. By noting the magnitude of current at intervals during the charging process, an idea is obtained of the amount of the charge. For example, suppose the duration of the charge be six hours, and the current during the first hour be three ampères, during the second and third hours two ampères, during the fourth one ampère, and during the fifth and sixth half an ampère, then the charge will be in ampères for each hour, 3, 2, 2, 1, $\frac{1}{2}$, $\frac{1}{2}$, or 9-ampère hours.

The method of charging accumulators from the electric light mains is described in the next chapter. See also Mr. J. T. Niblett's little book, *Portative Electricity*,* for much valuable information upon the whole subject of the management, care and charging of small accumulators.

The utmost vigilance must be perpetually exercised to guard against accidental or intentional short circuiting of any battery. Few batteries will stand short circuiting for many minutes; the dry batteries most used in medical practice are particularly sensitive to it. Short circuiting may easily occur if the electrodes are

* Biggs & Co., Salisbury Court, Fleet Street.

carelessly thrown down after use, and should happen to lie in metallic contact with each other.

When a battery has been dismounted and put together again, especially if it has many complex connections, there is a danger that the positive pole may have been accidentally connected to the binding screw marked negative and *vice versâ*. This is sometimes the case even when the repairs have been done by an instrument maker. This is an important point because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. It is easy to improvise one. A piece of wet litmus paper on a sheet of glass, will show by changes in colour at the electrodes which is the positive and which the negative pole. The ends of the wires from the battery must be rested on the paper for a few moments, electrolysis will take place and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Other reagents have been proposed, for example, a solution of phenol-phthalein in dilute alcohol answers very well, giving a purple red colour at the kathode or negative pole.

CHAPTER IV.

Dynamo Electricity.

The Dynamo Machine. Current Generators. The electric lighting mains. Direct and alternating current. Current from the main for medical and surgical applications. Regulation by resistances. Transformers. Dynamotors and motor dynamos.

63. **The dynamo machine.**—Commercial applications of electricity on a large scale would not be possible without the dynamo, because the primary battery, convenient as it is for some purposes, is altogether unequal to the work of producing electrical currents abundantly and cheaply. With the wide spread distribution of electricity from house to house by the electric lighting companies, the field of utility of the primary battery grows more and more restricted, and the current from the main is called into service for medical purposes wherever it is found. In this chapter the production of current by means of the dynamo machine, and other generators, and the technical details of adapting electric lighting currents for surgical and medical purposes will be considered.

In the near future there will not only be a great increase of public supplies of electricity for illuminating purposes, but the advent of electrically driven motor cars to take the place of horse traction will probably lead to the setting up of private dynamo sets in country places, and especially by medical practitioners, who will be glad to get rid of the troubles associated with horses

and to have instead an engine which will serve both to give them electric light at home and motive power abroad. A dynamo is a machine for converting mechanical energy into electrical energy by causing conductors to move in a magnetic field. It follows from § 40 that currents are induced in moving conductors if their movement is of such a kind as to cause them alternately to approach and to recede from a magnetic pole, and in a dynamo there is a fixed magnetic part or "field magnet" and a moving system of conductors or "armature" which rotates in the magnetic field between the poles of the field magnet.

64. **The field magnet.**—In the early days of dynamo electric machines this consisted of a permanent steel magnet or magnets. Instruments of this kind still survive, and under the name of "magneto machines" have had a certain vogue for medical purposes. Electro-magnets have now completely superseded permanent magnets for dynamos, and though the shapes seem to vary in different types of machines, all are essentially horseshoe magnets or groups of these. Oersted's discovery (§ 24 and § 26) of the magnetic properties of a wire carrying a current led naturally to the invention of the electro-magnet, for it was found that a soft iron "core" would be rendered temporarily magnetic by surrounding it with a spiral winding of copper wire and passing a current through the wire. For an account of electro-magnets see "The Electro-Magnet and Electro-Magnetic Mechanisms," by Silvanus P. Thompson.

The field magnet of a dynamo is an electro-magnet magnetised or "excited" by the passage of a current through the coils of wire wound upon it, the current for the purpose being usually taken from its own armature.

It is found that a slight permanent magnetism exists in all field magnet cores and this is sufficient to start small

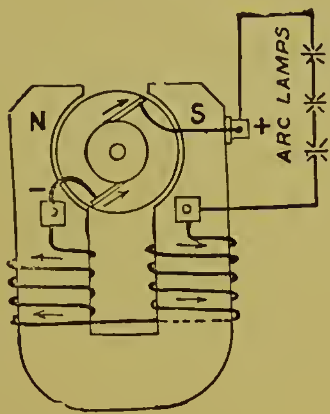


FIG. 19.—Series Wound Dynamo.

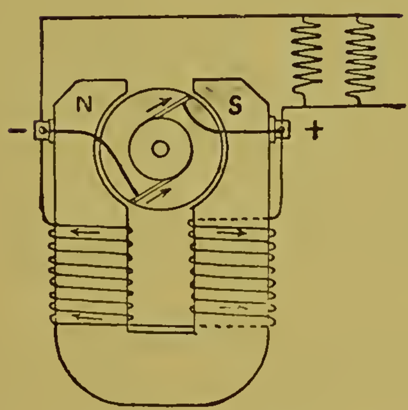


FIG. 20.—Shunt Wound Dynamo.

currents in the armature when it is rotated. These currents are made to traverse the field magnet and they

strengthen it so that it reacts more strongly on the armature until by the continuance of this mutual reaction between the armature and the field magnet the latter becomes fully magnetised. Thus a dynamo is a self exciting machine. The armature is mounted on a shaft provided with a pulley for the purpose of rotation and at one end of it is fixed the commutator which is built up of a number of copper or brass segments insulated from the shaft and from each other; the ends of the coil or coils of wire which form the armature are connected to these commutator segments, and when the armature is in rotation the segments pass in turn under the end of two collecting brushes which make contact with them. The commutator is a necessary part of a continuous current dynamo, for it serves to rectify the alternate currents generated in the coils during their rotation and delivers them to the field magnet coils and to the outside circuit as a series of impulses in one direction. When the whole of the current from the collecting brushes passes first through the field magnet coils and then through the outer circuit, the dynamo is said to be "series wound," the two portions of the circuit being in series, whereas a "shunt wound" dynamo has the field magnet coils in parallel or in "shunt" with the outer circuit (figs. 19 and 20). Each of these windings present advantages for certain purposes.

65. **Power for dynamo driving.**—A great increase in the use, by medical men, of electrical currents from storage cells has sprung up from the application of Röntgen Rays to diagnosis in surgery and medicine, and the use of storage cells brings the need of current for charging them. Primary batteries are of no use for driving the large induction coils which are commonly

employed for X Ray work, and to use them indirectly for charging accumulators soon becomes tiresome. In many places the recharging can only be done by sending the accumulators to a dynamo station at a distance and the transportation of accumulators is expensive and troublesome and is by no means conducive to the long life of the cells. On the other hand it is rather a formidable undertaking for a medical man to set up a private dynamo for charging his accumulators, and especially so because it is difficult to procure a plant which is satisfactory without also being too big. One needs not only the dynamo, but also the power to drive it, and it is difficult to find good engines of very small power, as small machines are apt to be as expensive to make as bigger ones would be, and there is no large demand for them.

Manual power, windmills, water motors, hot air motors and gas and oil engines have all been applied to the driving of dynamos. In any particular case the local conditions will help to decide which is likely to be the most convenient source of power. To charge an accumulator from a dynamo is not so entirely simple a matter as may be supposed, and will be referred to again below. The E.M.F. of the charging source must be maintained steadily above that of the cells to be charged, for if this is not done the cells will discharge back through the dynamo, with a result quite opposite to that desired. On this account manual power is apt to be too unsteady for charging purposes. By adapting a bicycle and so making use of pedal power, the Crypto Cycle Company of Clerkenwell have contrived a fairly useful apparatus for dynamo driving, and it is interesting to note that the electricity required for charging accumulators in the Soudan campaign for Röntgen Ray

work was generated by means of an apparatus of this kind, a tandem bicycle being so converted as to drive the dynamo by means of a belt from the hind wheel. See the illustrated paper by Surgeon-Major Battersby in the *Archives of the Röntgen Ray* for February, 1899.

In many places a small windmill would be of great use for charging a few storage cells, and probably a small outfit comprising a windmill and dynamo might sell advantageously in country places.

Where there is a cheap water supply a water motor can be made to work with very little trouble, and would be a useful contrivance, but water motors consume much water. There are several forms of water motors in small sizes, which can be had from the makers of philosophical instruments.

The hot air engine sold by Messrs. Norris and Henty* under the name of the Robinson Hot Air Engine, and another form sold by Messrs. Baird and Tatlock are handy little things, but only give about one twenty-fifth of a horse power, and it is worth no one's while at present to make a dynamo of that small power, which shall convert the mechanical into electrical energy with any approach to efficiency.

Messrs. Vandervell, Thorpe Works, Notting Hill, W., make a gas engine of one-eighth horse-power which can be used to drive a dynamo for charging storage cells. It is a good little engine, and would probably answer for charging purposes quite well in the hands of anyone who was willing to take a little trouble to get to know it thoroughly. They quote for the engine alone £4 10*s*., or with dynamo mounted on iron bed plate £7 7*s*. They recommend, however, a small further outlay so as to provide a better dynamo, which would make the

* 36 Upper Thames Street, E.C.

combination work more steadily. In the larger size of one-half horse-power one begins to reach practical and good gas and oil engines. The Gardner Engines, for gas and oil (Norris and Henty as above), cost £15 and £25 respectively at this power, and can be specially provided with dynamo, pulleys, belts, etc., complete at £26 10*s*. and £36 10*s*. With one of these sets the charging of storage cells can be effectively dealt with. The Pittler Company (144 High Holborn) also list a "one man" power gas-engine at nine guineas. When

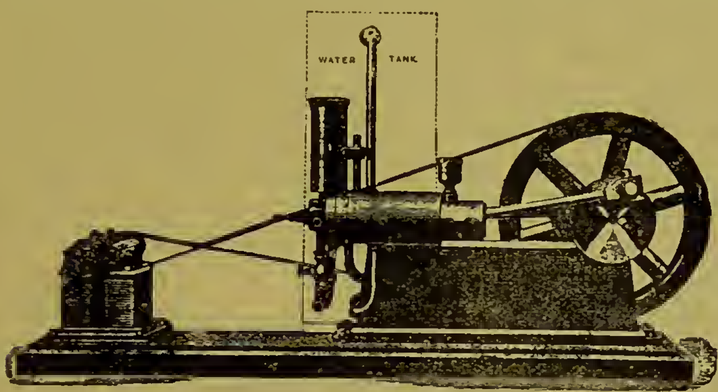


FIG. 21.—Vandervell's Gas Engine.

charging an accumulator from a dynamo the possibility of an unexpected stoppage of the machine must be borne in mind. To meet this possibility automatic switches have been contrived which at once cut off the cells from the dynamo circuit if anything goes wrong. This is necessary to prevent the charge already accumulated in the storage cells from running down through the dynamo circuit to the probable damage both of dynamo and cells. When the dynamo is running its polarity must be verified (§ 62) before joining up the cells to it.

66. **Current from electric lighting mains.**—It will be seen from the preceding paragraphs that the generation of electricity in small quantities in one's own household is surrounded with difficulties. Those who live in a place where there is a public supply of electricity are spared these difficulties and only require to know the capabilities of the supply at their command and how best to adapt it for their professional requirements. For this it is necessary in the first place to know whether the public supply is direct or alternating, secondly, the voltage or pressure of the supply: thirdly, in the case of alternating current, the periodicity or frequency of the alternations. In Appendix A is set forth a list of the public supply stations in Great Britain and Ireland, with particulars of these details.

The difference between direct and alternating current consists in the former being a steady flow of current from the one conductor or lead through the lamp (or other appliance) to the other. The one wire is always positive, the other always negative. In the alternating supply the current flows in a series of pulsations in both directions, each wire being in turn either positive or negative. The pressure at which electric lighting currents are supplied to houses is usually 100 volts, in some places 103, 105 or 110. At the present time a gradual change to 200 as the standard pressure of supply is taking place, with the object of saving expense in mains. At 200 volts a given current represents twice as much energy (§ 39) as the same current at 100 volts, so by doubling the voltage of supply the conductors are enabled to carry a double load without the need for increasing their sectional area. See § 29 on Resistance of Conductors. There is no special advantage to the consumer from the higher voltage, but rather the

reverse, but the advantage to the supply companies in the saving of capital outlay on copper for mains is considerable.

The uses to which the current from the mains may be applied are as follows:—

1. To illuminate cystoscope lamps and other small lamp instruments.

2. To heat a galvano-cautery.

3. To drive dental and other small motors.

4. To operate large induction coils for X Ray work, ozonisers, &c., and medical coils.

5. To charge accumulators.

6. To replace medical batteries in the treatment of patients.

For all these purposes it is important to know whether the supply is direct or alternating, because the nature of the apparatus will depend primarily upon this point. Either direct or alternating current can be used for heating a cautery, for lighting up lamps or for driving motors. The alternating current cannot be made to charge accumulators nor to work large coils, nor to replace a constant current battery. It can, however, be made to take the place of a medical induction coil with certain limitations. Perhaps, it may help to make the differences between the two kinds more readily intelligible if it be borne in mind that the direct current is more like a battery current, and the alternating current more like the current of an induction coil. It will be convenient to take two cases and deal exhaustively with each; one, the case of a medical man with direct current at command, and the other, that of one with alternating current laid on.

67. **Direct current resistances.**—In almost all applications of the current to medical practice the first

need is for means of reducing the pressure. The pressure of supply (100 volts or upwards) is too great for any of the medical purposes just enumerated, except for the driving of some electro-motors. In order to reduce the pressure resistances are employed, for by means of the resistances in a circuit the magnitude of the current in the circuit can be regulated (*see* § 31, Ohm's law). Thus a resistance of 100 ohms in a circuit of 100 volts will prevent the current from exceeding one ampère and a resistance of 100,000 ohms will cut down the current to one milliampère and so on.

It is important to distinguish between the effect of a resistance in cutting down the current in a circuit, and its effect in lowering the voltage in a circuit or portion of a circuit. In § 45 when treating of internal resistance an attempt was made to draw this distinction, and it must now be repeated that the effect of a resistance upon the voltage in any part of a circuit is a relative one, that is to say the fall of volts in a part of a circuit, such as a resistance, depends upon the resistances of the other parts of the circuit, and may be estimated by comparing the resistance of the part under consideration with the resistance of the rest of the circuit. For instance, take a resistance of 99 ohms interpolated in a circuit of 100 volts, when the resistance of the remainder of the circuit is very small, say, for purposes of illustration, one ohm, then the drop of volts in the resistance will be 99 volts. But if four such resistances be inserted in different parts of the same circuit then the drop in volts at each resistance will no longer be 99 volts, but will be one quarter of that amount, and the fall in the potential from 100 to 0 will take place in four steps of about 25 volts, one at each resistance. It follows from this that a resistance intended for regulating the voltage in any

part of a circuit must be made proportional to the resistance of the circuit to be regulated. If the resistance of the part to be regulated is 50 ohms then a resistance of 50 other ohms will halve the voltage acting on it, but a resistance of 50 ohms will not equally halve the pressure if the other part has a resistance of 950 ohms, for in this case the fall in volts at the first resistance would only be one-twentieth of the total voltage of the circuit, while the second portion would bear a voltage of nineteen-twentieths of the total. A resistance which is suited for the regulation of the current of a lamp will not serve to regulate current through the human body. In the first case a few ohms will suffice, in the latter a few thousand ohms are necessary.

68. **Resistance instruments.**—It was stated in § 39 that the energy expended when a current passes through a resistance appears for the most part in the form of heat. Resistances, therefore, become heated when in use, and the heating effects must be carefully borne in mind and the resistances designed to carry the currents they are intended to regulate without excessive heating. A resistance suitable for a current of a few milliampères might be burnt out if a current of one ampère were passed through it. As a general rule the larger the current to be controlled the bigger and stronger and more expensive the controlling resistances become. From their cheapness and convenience incandescent lamps are often useful for resistances as they are not injuriously affected even by great heating, and in almost all resistances for medical use an incandescent lamp of eight or sixteen candle power forms part of the circuit, being combined usually with a coiled wire resistance which admits of adjustment. On a circuit of

100 volts a sixteen candle power lamp will cut down the current to about ·6 of an ampère. An eight candle lamp to ·3, and a thirty-two to 1·2 ampères. By always working through a lamp the maximum current can be kept down within these very moderate limits and thus trouble with the safety fuses and risk of damage to the galvanometer coils or other delicate apparatus may be avoided. As a rough approximation the resistances of incandescent lamps may be taken as follows:—For 100 volts; an eight candle lamp 320 ohms, a sixteen 160 ohms, a thirty-two 80 ohms. With 200 volt lamps the resistances are double of these. The ordinary way of using a resistance is to put it in series with the apparatus to be protected. The whole current then passes first through the resistance and then through the apparatus regulated. But another way of using resistances is to have them as a shunt or bridge to the piece of apparatus, the current dividing and part passing by the one channel and part by the other. When two circuits are arranged in this way, in parallel, either of them is said to be "in shunt" to the other, or "shunted by" the other. Arrangements of resistances in series or in shunt to apparatus are often useful, or two resistances may be used in series with each other, the patient (or the piece of apparatus) being arranged as a circuit in shunt to one of them, and figure 22 shows such a combination of resistances. The current from the main passes from the positive pole of the supply through a switch to A. From A to B is a resistance of wire, B is a lamp which the current traverses to reach the negative pole, after passing through a fuse. Thus there is formed a closed circuit through the two resistances of the wire coil and of the lamp with a fall or slope of potential between A and B and a further fall through the lamp at B, the total fall

being from 100 volts to zero on a 100 volt circuit. The circuit for the patient, or instrument, is arranged in a shunt to the wire resistance, and the voltage, acting upon it, will be varied by moving the traveller C along its metal slide. Let us suppose that the coils depicted are 450 in number, and that their resistance is nine times as great as that of the lamp B, then assuming our pressure at the main to be 100 volts, the drop of volts in the lamp will be 10 volts and in the coils 90 volts. With 450 coils in the wire the fall of volts is one-fifth

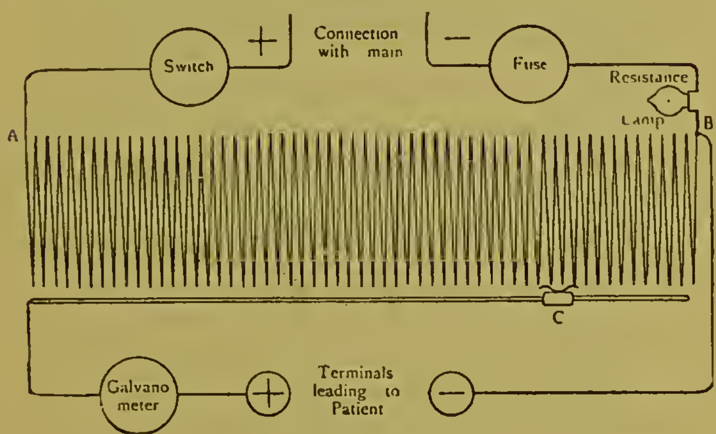


FIG. 22.—Plan of resistance in shunt to a pa ient.

of a volt per coil, that is to say there will be a potential difference of one-fifth of a volt between any coil and the next. If the coils were 4,500 in number then the potential differences would be as one volt for every 50 coils, and so on. The potential difference between C and B through the shunt circuit would increase as the traveller C was moved further from the B end of the coil, because it would "tap" the slope of potential at a higher level, so to speak, and the more numerous the coils of A and

B the more finely could the volts be adjusted to suit any needs of the shunt circuit.

With certain structural variations, chiefly in the number of the windings and the thickness of the wire, this method will suit all the cases which require a low pressure to be obtained from the electric light mains. The lamp acts as a safety resistance and determines the maximum current which can pass through the apparatus. A certain latitude is afforded by the use of lamps of various candle power for the safety resistance. When the current is to be applied to the lighting of a small surgical lamp which requires, say, an ampère, the safety lamp must be of such a character as to permit that current to pass it. When a cautery is to be heated no lamp is arranged in series with the coil and the various parts must be on a much larger scale, because they have to waste energy at the rate of two horse-power when in use, and the current of from five to twenty ampères which a cautery requires has considerable heating effect upon the wires which lead to the cautery as well as upon the cautery burner itself. The immediate application of a direct current from the mains to the commoner requirements of medical practice is fully met by a set of resistances arranged to give slopes of potential, with sliding contacts for varying the pressure in the shunt circuits in which the patient or the apparatus is arranged. These things can be had mounted ready for fixing to a wall or table from Mr. Schall (*see* fig. 23).

69. **To charge accumulators.**—Unless a special point be made of working only from the main direct, one may use the direct current to charge accumulators in the first place; the accumulators can then be detached from the mains and used independently. In

the former case there will still remain the need for providing a portable apparatus to take to a patient's

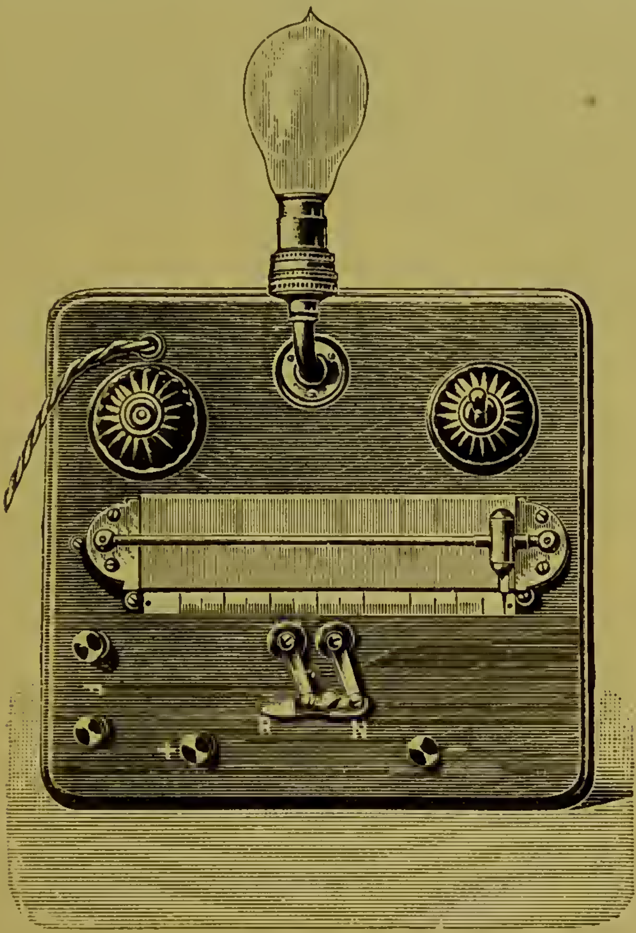


FIG. 23.—The terminals at F are for charging accumulators, or for working a medical coil; the terminals marked +, —, for direct applications to patients.

house. Although a desire for absolute uniformity of practice, or the idea of saving oneself trouble, might make one wish to use current from the mains only,

without any accumulators, the advantages on a practical side all lie in a combination of the two methods, that is to say in the use of accumulators for some purposes, and in direct applications of the current from the mains in others. Thus by far the simplest way, and the cheapest, for lamp and cautery work, is to charge a portable accumulator from the mains, and then to use it

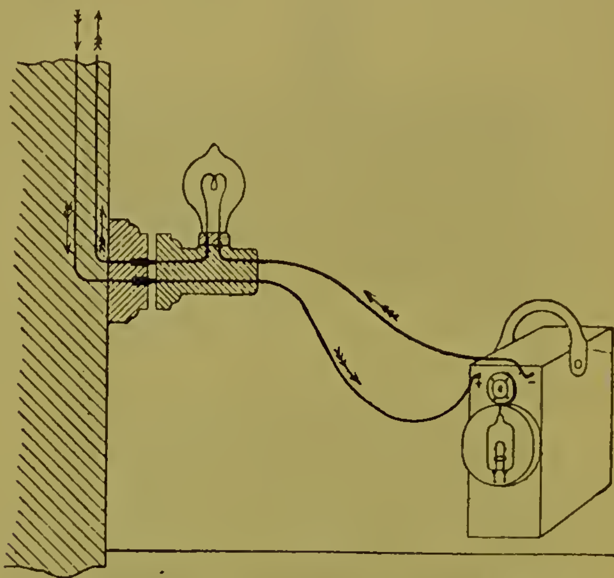


FIG. 24.—Charging an accumulator from the electric light mains.

detached, for the lamps or cautery. Many surgeons only use electricity for these purposes and with a small portable accumulator and a plug arrangement for recharging it, they can be fully equipped at a small outlay.

To charge an accumulator from the direct current mains is easy. A plug of special construction (fig. 25) with a lamp is needed. The current passes through the

lamp to the accumulator, as shown in fig. 24, the lamp serving as a protecting resistance. The accumulator is connected by wires to the two binding screws shown in fig. 25. To charge from a concentric wall plug, or from an Edison-Swan screw lamp socket is best, because such a plug can only fit into its socket in one way and the positive and negative terminals are always the same (*see also* p. 78). With a lamp socket of the ordinary bayonet-catch pattern there would be a right and wrong way and the polarity of the terminals

FIG. 25.—Lamp resistance for charging secondary cells from the mains.

needs testing each time (see § 62, pole testers). A rough and ready way to test the direction of the current when charging secondary cells is to notice the brightness of the lamp when the accumulator is coupled in, for when joined correctly for charging the brightness of the lamp is lessened, whereas the lamp glows

more brightly when the connections through the accumulator permit of its discharge. If the experiment of connecting up in each direction be tried a few times the difference in the brightness of the lamp will soon be appreciated.

When the charging of the cells from the mains is to be done regularly it may be worth while to have the charging terminals connected to some one of the house lamps which is in regular use, in order not to waste energy. As the electromotive force of the cells which are under charge is opposed to that of the charging circuit, the lamp will be dimmed to a certain extent by the counter-electromotive force of the cells, this can be met by using a lamp of lower voltage. Thus on a 100 volt circuit a 90 volt lamp in series with an accumulator of four cells (8 volts) would be brought to full incandescence and would give a good light while the accumulator was being charged.

70. **Alternating currents. Transformers.**—The general limitations of the alternate current supply for medical work are given on page 89. There the alternating current was compared to the induction coil current, for which see Chap. V. It cannot, however, be conveniently used for general purposes in testing nerves and muscles nor in treatment except through the medium of a bath (see Chap. VIII., "The Electric Bath") as when applied to the skin in the usual way by means of pad electrodes the sensations it causes are unpleasant.

The main feature of convenience which alternate currents have lies in the ease with which they can be made to induce fresh alternating currents at any desired voltage. With continuous currents, as we have just seen (§ 68), the voltage of supply can be cut down by means of resistances, which may also be used with

alternate currents, but by means of a transformer the pressure of supply of an alternating current can be changed into any other pressure, higher or lower, as may be desired, and that without the waste of energy which occurs in the case of resistances. Thus by a transformer the energy represented by a current of one ampère at 100 volts can be transformed into a current of 100 ampères at one volt, or into a current of one-hundredth of an ampère at 10,000 volts, subject only to small losses in the apparatus.

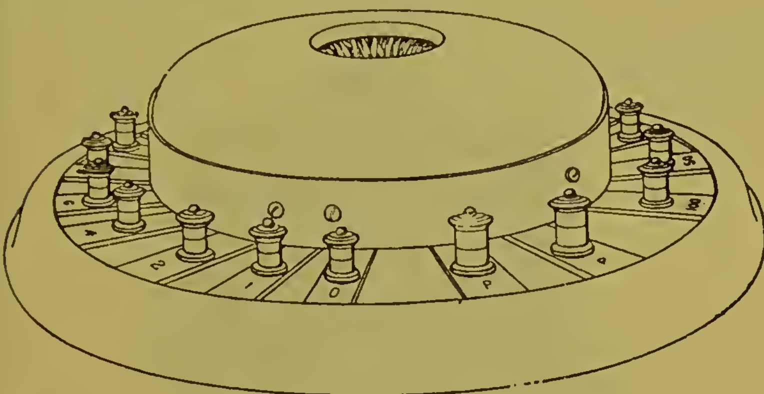


FIG. 26.—Graduated transformer.

The principle of the transformer is that of the induction of a current in a wire by a variable current in a neighbouring wire (§ 40), and the transformer consists of an iron core wound with two distinct windings of insulated wire. These may be called the primary and the secondary windings, and the variable E.M.F. impressed upon the primary when it is connected to a system of alternate current supply will induce a variable E.M.F. in the secondary, having a voltage which will depend upon the ratios of the number of turns of wire in the primary and secondary coils.

The commonest type of transformer for medical use is one which is used to convert a small current at 100 volts into a larger current at two or four volts for cauteries, or at eight or ten volts for small incandescent lamps, or for use in the electric bath, while, occasionally, transformers may be required to give out high pressures

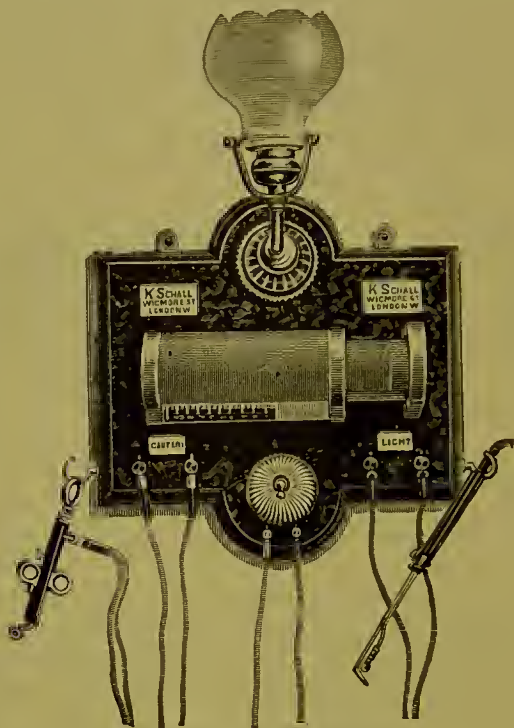
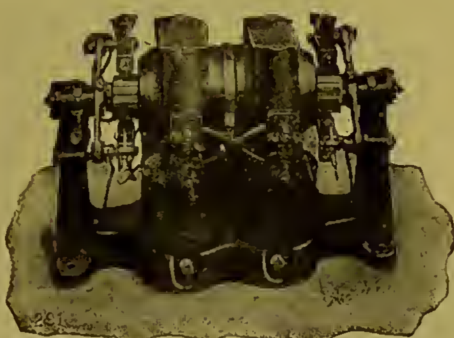


FIG. 27.—Woakes' transformer.

of many thousand volts for generating ozone, or working Tesla high frequency coils.

A well-known type of transformer for medical use is Woakes' transformer. It has several secondary coils all wound upon one bobbin; one for cautery to give

about two volts and wound with thick wire to carry a heavy current without heating; one for small lamps, and one for therapeutic purposes. Each secondary has its own terminals, and all are excited by one primary coil. Regulation is effected by a sliding arrangement which serves to bring the secondary coils towards the primary coil or away from it. In other forms of medical transformer the iron core is not straight as in Woakes' pattern, but is a circular ring of laminated iron. This is more efficient electrically, but less convenient for regulation. Fig. 26 shows a ring transformer which has a secondary tapped and brought out to binding screws at intervals, thus affording a means of obtaining a great variety of voltages from one



28.—Motor Dynamo. A motor and a dynamo combined on one axle.

instrument. Others again are made with a moving arm which takes up into circuit more or less of the windings of the secondary, and so gives very good regulation of voltage.

71. **The conversion of direct current into alternating and vice-versa.**—It sometimes happens that a consumer upon one system of supply desires something which can only be had from the other system; thus a con-

sumer in an alternate current area may wish for direct current to charge accumulators, or a consumer on direct current may wish for alternate current for an electric bath or for use with high voltage transformers. Various devices have been proposed for fulfilling these objects; for example, a motor driven by the current supplied in the district is made to drive a dynamo built to give out the kind of current required. In some cases the two machines have been combined into one compound machine with greater or less success. The General Electric Company stock these under the names of dynamotors or motor dynamos, and supply them for battery

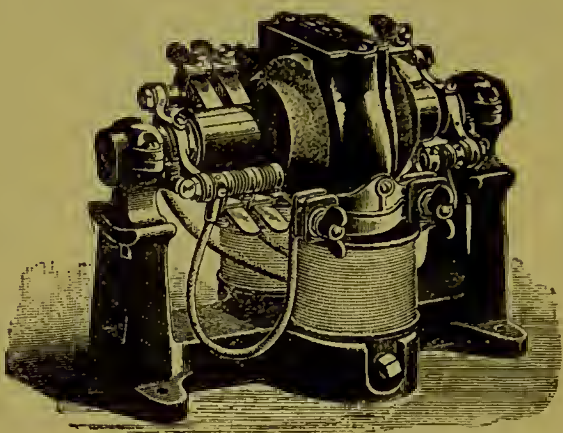


FIG. 29.—Dynamotor. Two sets of windings upon one armature.

charging; that is to say for the conversion of a continuous current at high voltage into a continuous current of greater magnitude at a lower voltage, and for bell-ringing, that is for generating an alternating current of low voltage from a direct current at 100 or 200 volts. When the conversions have to be from alternating o continuous current one must have recourse to two

separate machines, an alternate current motor driving a direct current dynamo. The apparatus can easily be contrived but owing to its cost medical men are as a rule content to do without it, there is therefore no good ready-made instrument of this type as yet on the market. The Langdon-Davies Motor Company make a good motor for alternating currents, from one-half horse power upwards, and one of their instruments connected by belt or otherwise to a direct current dynamo of corresponding size will effect the conversion of alternating into direct current. The dynamo must be wound to suit the voltage and current required from it.

CHAPTER V.

The Induction Coil. Conducting Wires. Binding Screws. Electrodes. Current Collectors. Commutators. Regulation of Current. Galvanometers.

72. **The induction coil.**—One of the most interesting of the early observations in connection with electromagnetic induction was, that shocks and sparks could be produced from a single galvanic cell if its circuit contained spiral coils of wire. Indeed, it is possible that Faraday's researches into the phenomena of induction may have been started in that direction by a question asked of him at the Royal Institution, as to why a shock was felt when a circuit containing an electro-magnet was broken, although no shock was felt if the circuit contained no magnet nor coils of wire. In § 42 it has been mentioned that these effects depend upon the self-induction of the circuit; and very shortly after the publication of the researches of Faraday and of Henry in 1831 and 1832, the subject was taken up by others, and coils were made by Page, Sturgeon, Callan, and others, which were the prototypes of the modern induction coil.*

The peculiar physiological effect or shock which these induction coils produced soon led to their application to medical treatment, and in 1837 a machine contrived for this purpose by a Mr. Clark, was figured† in Sturgeon's *Annals of Electricity*. Others

* For a full and interesting account of the early history of the induction coil, see Fleming, "The Alternate Current Transformer."

† See Fleming, *op. cit.*

quickly followed, and the drawings of the period commonly represent these coils as fitted with handles for patients to grasp, showing the general idea of the mode of employing them in therapeutics. By the introduction of the separate "secondary" coil, and of the automatic contact breaker, the induction coil acquired its modern form, and the researches of Duchenne into the different physiological effects of long and short coils was an application of the principles already foreshadowed clearly by Henry's experiments with long and short wire spirals.

Since then the medical induction coil has undergone many modifications at the hands of ingenious instrument makers, but few of these modifications have been of much value, because the principles determining the physiological action of the coils have received but scant attention.

It is convenient to consider the phenomena of the induction coil as depending on the magnetic field of force (§ 26), which exists round a wire carrying a current. When such a wire is wound into a helix, this behaves as a magnet, and the magnetic lines of force of a straight helix are arranged precisely like those of a bar magnet (see fig. 4). If a bar of iron is inserted into the helix, the magnetic permeability of that portion of the magnetic circuit becomes increased, because iron conducts magnetism several hundred times better than air does, and consequently more lines of force will traverse the helix for the same strength of current in the wire, and the magnetism of the helix will be increased. The magnetic field set up in the helix at the moment of closing the battery current reacts upon the wire and produces in it a wave of opposing electromotive force which retards the growth of the current so

that it does not instantaneously reach its full strength, and the collapse of the magnetic field at the moment of breaking the current also sets up a wave of electromotive force in the wire which strengthens the battery current and shows itself by a bright spark at the place where the circuit is broken.

In its simplest form the induction coil consists of a coil of insulated wire wound upon a reel or bobbin with an arrangement, usually a vibrating spring, for automatically closing and opening the circuit. When a current passes through it the spring comes into play, and the current is periodically established and interrupted, and so the magnetic field of the apparatus is caused to vary with every make and break of contact, and induction currents are produced in the wire coil. The induced current at break can be led off by properly arranged conductors and is known as the primary current, or the extra current; the other does not leave the apparatus but expends itself in the closed circuit formed by the coil and the contact breaker. The primary current is therefore a series of impulses or waves, all passing in the same direction, and corresponding in time and frequency to the interruptions of the contact breaker; each wave is due to a sudden rise of electromotive force in the wire, followed by a more gradual fall, the whole time of each wave being a very small fraction of a second, and varying considerably in different coils.

The secondary current of an induction coil, as its name suggests, is derived from another entirely independent coil wound upon the same bobbin as the primary coil. Being in the same magnetic field as the primary coil it is acted upon in the same way, but the effects produced in it are not quite the same, because

they are quite free from the battery current which flows in the primary coil. In the secondary coil there is an induced electromotive force corresponding to the rise of magnetism and an opposite electromotive force corresponding to its fall. Both of these give rise to currents through an external circuit, and because they are in opposite directions the currents from the secondary coil are said to be alternating. They are not exactly alike in all respects, although the total flux of electricity is the same in each, for the electromotive force at the break of the primary current is higher, and the duration of the wave is shorter, than at the make, because, as has been seen, the rise of the magnetising current in the apparatus is more gradual than its fall.

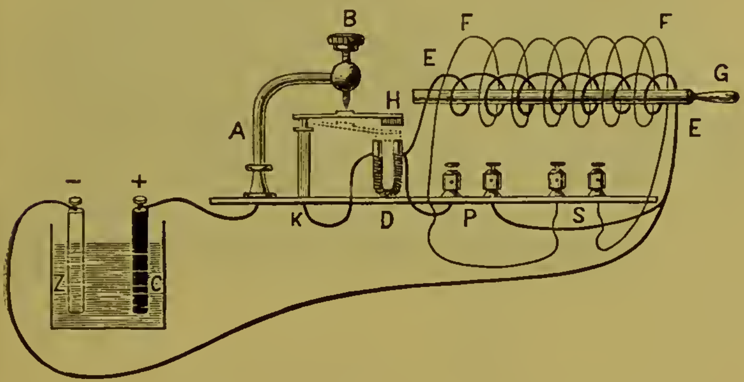


FIG. 30.—Arrangement of wires in an induction coil.

The electromotive forces developed by induction in the primary and secondary coils vary very much in different instruments. In both coils the electromotive forces reach maxima which are higher than that of the battery which supplies energy to the apparatus.

Fig. 30 is a plan of the arrangement of the wires in an induction coil, and fig. 31 shows an actual coil.

The lettering is the same in both of the figures. One pole of the battery is connected to the binding screw A. The current then passes by the adjusting screw B, the vibrator H, and the support K to the horseshoe magnet D. After traversing this the circuit gives off a branch to the binding screw P, and is continued to the primary coil EE, the return wire from which again gives off a branch to the second binding screw at P, and is then continued to the other pole of the battery. The

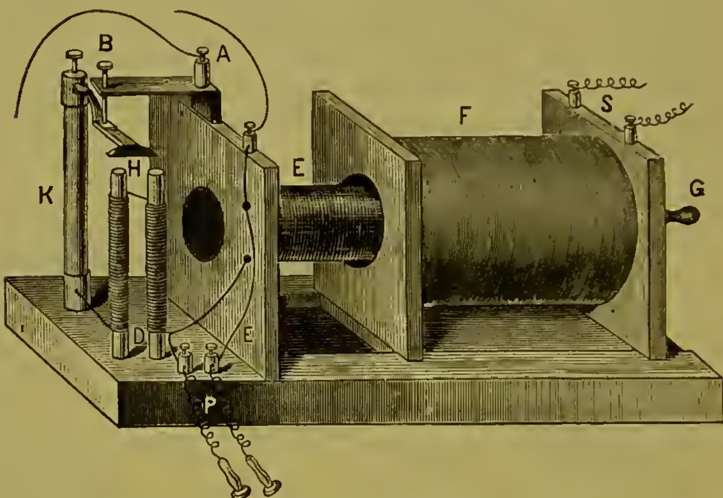


FIG. 31.—Induction Coil.

two binding screws at P are thus in connexion with the two ends of the primary coil, and by means of electrodes attached to them the patient may be treated with the primary current of this coil. The secondary coil F is wound on a separate hollow bobbin and has its terminals at S. This bobbin is made to slide like a sledge on guides so that it can be made to approach or recede from the primary coil. At G a handle is seen attached

to the iron core which can slide in and out of the primary coil, and so further regulate the induced electromotive force set up in both the primary and secondary coils, by varying the strength of their magnetic field.

Another and somewhat neater form of sledge coil is shown in fig. 32. The general plan of construction is

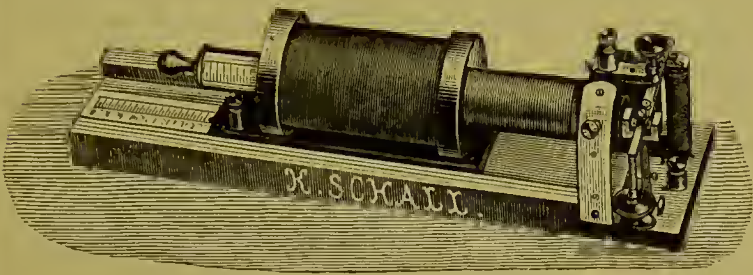


FIG. 32.—Induction coil.

the same as in the last figure, with the addition of divided scales by which the relative positions of primary, secondary, and core can be recorded and results verified. It must be borne in mind that the readings of the scale are not at all in proportion to the electromotive force or the current induced in the coils, they merely make it easy to reproduce a given condition at will.

The mode of action of the automatic vibrator or contact breaker is clearly shown in the figures. The electro-magnet, by drawing down the spring H, breaks the circuit at the point of the screw B, whereupon the attraction of the electro-magnet ceases and the spring is released, and flying up re-establishes the circuit; the action is then repeated, and the spring is kept in constant movement. By turning the screw B, the pressure upon the spring and its rate of vibration can be modified. Instead of the separate electro-magnet it is easy

to utilise the magnetism of the iron core for working the contact breaker, and this is done in those patterns of medical coil which have a fixed core; but in these coils some mode of regulation other than that of a sliding core is required.

In order that the coil may be used for medical purposes there must be some method of regulating its strength. The following methods are in actual use in medical coils:—

1. By the use of a sliding core to vary the strength of magnetic field in the coils.

2. By the use of a metal tube to slide over the core and so shield the coils from its action.

3. By the use of a secondary coil (sledge coil) which can be brought into stronger or weaker parts of the magnetic field.

4. By a switch for progressively taking up into the circuit greater or lesser portions of the coils.

The variety of coils in the market is very great, and they can be had either separate or fitted up in a box with a battery to drive them, and with a drawer to hold wires and electrodes; this is convenient, as it makes them more portable. An inspection of an instrument maker's illustrated catalogue, or better still of his stock, is the quickest way of becoming familiar with the types of coil in general use.

In choosing an induction coil the points to be attended to are as follows:—

First, to see that the vibrator works smoothly and evenly; this is very important, as many coils are defective in this respect, and give an irregular series of shocks of unequal strength, which is unpleasant for the patient; before buying a coil it is a good plan to have it set in action, and to test it upon one's self. In this

way it is easy to learn whether it works evenly; and, secondly, whether it permits of satisfactory regulation of its strength; thirdly, the coil should be quiet in action; fourthly, it should not require a large current, or else the cell used to drive it will require frequent renewal.

The induction coil is most commonly used to excite muscular contraction, either for purposes of testing or for treatment, but it is also used for its action upon sensory nerves. In the first case a low electromotive force is best, but for the latter a high electromotive force is needed, and in the best instruments two separate and interchangeable secondary coils are provided, one of a smaller number of turns of wire, and one of a very large number of turns, then either coil can be used as the case under treatment requires. Duchenne showed that the physiological effect of a coil of fine wire with many turns, differed from that of a short coil of few turns and thick wire, and his observations on this point may be expressed in modern language as follows:—With a short coil of two or three hundred turns, the electromotive force is low, but it is sufficiently high to excite contractions in the muscles if the skin be properly moistened. A long coil of many turns, two or three thousand, gives a high electromotive force, and when applied to the surface of the dry skin, with dry electrodes, it acts powerfully in spite of the great resistance offered by this mode of application. It is therefore useful in cases in which the short coil will not act.

On the other hand, the long coil is less useful for stimulating deep seated muscles, because it has a high resistance and a still higher impedance, which behaves as an enormous additional resistance, and therefore its available electromotive force may be several hundred

volts when the external resistance is very high, and yet may be comparatively low through a resistance like that of the well moistened skin. This may be compared to the behaviour of a galvanic cell of high internal resistance, whose available voltage for a circuit of low resistance may be only a small fraction of its electromotive force on open circuit (see § 45).

A particular secondary coil was tested by means of an electrostatic voltmeter, and the potential difference at its terminals came out at 89 volts. With a non-inductive external resistance of 1000 ohms, in shunt to the voltmeter, the potential difference fell to ten volts.

Another way of expressing the difference between long and short coils is to say that the short coil gives a lower voltage but a larger current, while the long coil gives a high voltage and only a very small current; the large current is able to influence deep muscles because it is not so much dissipated by diffusion through the tissues as is the case with the small current. And, on the other hand, the small current of the fine coil makes itself sharply felt at the point of entry through the skin, but is scattered by diffusion through the underlying tissues, and there is not sufficient density of current in the muscles to affect them. The fine coil should be used with a wire brush electrode, or other electrode of small surface, as this concentrates the current at the points of contact, and produces effective stimulation there, with little or no effect upon parts which are further removed.

Most of the coils in common use have intermediate properties, because the number of their windings is neither very small nor very great, and they are therefore not so well suited for the special purpose of stimulating the sensory nerves of the skin or the mucous

membranes, without affecting the deeper parts at the same time. Duchenne has maintained that for the treatment of neuralgic pains the use of a current from a short coil is injurious, because it produces muscular contraction, and affects the deep structures, whereas the action should be limited to the surface, and patients will usually say that the pain is increased by the treatment if a short coil is used.

73. **Long and short secondary coils. Thick wire and thin wire coils.**—The difference between a short coil of thick wire and a long coil of fine wire, depends very much more on the number of turns than on the diameter of the wire, for the ohmic resistance of the wire is only a small part of the total impedance of the coil. One secondary coil can therefore be made to take the place of two or more separate coils, if by any means the number of turns in actual use can be varied. This may be done by tapping the secondary coil in several places, and bringing out a wire from each place tapped to a separate binding screw. Coils of this kind can be had, in which one-third or two-thirds, or the whole number of the turns, can be used at will.

It is difficult to specify precisely what is the most suitable number of turns to give the short coil or long coil effects. In Duchenne's instruments the short coil seems to have had about 500 turns, and the long coil about 4,000, but this is only a guess, as he merely states the lengths of wire used. But the number of turns is not the only factor concerned, and these figures will suffice to indicate the general proportion between the two coils.

74. **Frequency of interruptions.**—The interesting results obtained from currents of very high frequency

of alternation, which have been so ably developed by Elihu Thomson, Tesla, D'Arsonval, and others, has turned the attention of medical men to the study of the contact-breaker of the induction coil, and coils can now be bought with regulating devices to produce at will almost any rate within comparatively wide limits, as, for example, from one vibration to two hundred per second in Ewald's coil (fig. 33). In this the vibrator

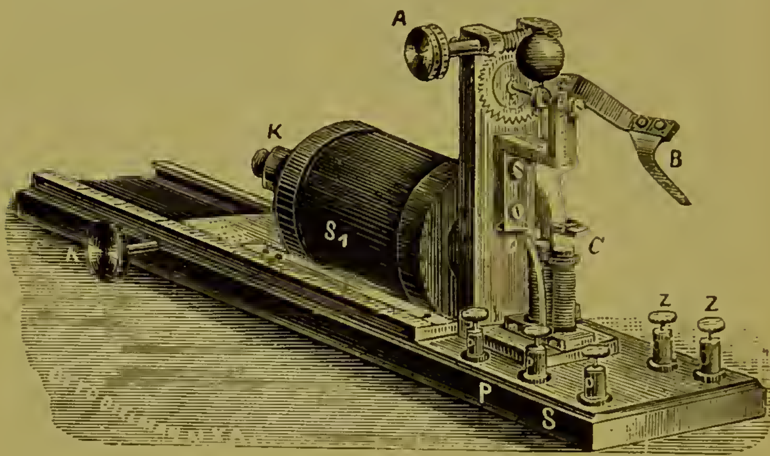


FIG. 33.—Ewald's coil.

has the form of a pendulum C, swinging between two springs B and D. B can be altered in position by means of the screw A, and so controls the range of swing of the pendulum. Other coils again are fitted with a break, "the singing rheotome," which vibrates so rapidly as to emit a high pitched note, estimated at 500 per second. None of these rapid breaks, however, really attain to the conditions of true high frequency, which can be obtained with Leyden jar discharges, for these may have a period of oscillation equal to hundreds

of thousands or even millions per second, a rate which is a thousand times more rapid than that of the most rapid mechanical contact-breaker.

The average rate of vibration of the contact-breaker in common use in medical coils is about fifty per second.

Much work remains to be done before our knowledge of the influence of varying frequency of vibration can be considered satisfactory. It is very probable that the sensory nerves respond differently to vibrations of different frequencies. For instance, the heat vibrations emitted by warm bodies, and felt as a sensation of warmth, are at a rate of billions per second, but yet can easily be distinguished by the nerve endings from other forms of tactile sensation.

If the impulses are so infrequent that the muscle has time to relax between its successive contractions there is more commotion of the muscle, and greater discomfort than when it is maintained in a condition of tetanus; to produce this requires about 20 impulses per second.

The decreased effect of a coil whose contact-breaker is vibrating rapidly, is mainly due to the fact that the exciting current has not time to rise to its full value before it is broken again, consequently the magnetisation of the core, and the induction in the secondary coil do not rise so high as they would if the same coil were worked at a lower speed.

Duchenne preferred a rapid vibrator for acting upon sensory nerves, and for certain conditions of muscular atrophy and for stimulating muscles when they would not respond to slow interruptions, or had lost the muscular sense; for general purposes of muscular stimulation he advises slow interruptions, and prefers them in treating muscles paralysed by cerebral lesions,

because the slow stimuli acting less upon sensory nerves are less likely to set up reflex irritation at the seat of lesion in the skull. He believed that rapid vibrations might hasten the degeneration of muscle in certain cases. His slow vibrations were sometimes of the rate of one or two per second.

From 40 to 60 vibrations per second is a very suitable rate for testing and treating muscles; at higher speeds a peculiar benumbing effect makes itself felt when the electrode is applied over a sensory or mixed nerve trunk; this numbness is felt over the area of distribution of the nerve, and with it a strong but not painful vibration is felt all along that part of the nerve trunk which extends from the point stimulated to the periphery. It does not extend upwards along the nerve trunk, but is referred to its distal parts, very much as is the case with the ulnar nerve when it is struck or pressed at the internal condyle of the humerus, and produces pain or tingling in the ulnar side of the hand and fingers.

Much has been made lately of the important differences in effects which depend upon the rate of the contact breaker, and the number and fineness of the coils of wire. In gynæcology especially the long coils and the fine wire are insisted on. In the United States, now-a-days, very highly finished coils are made and sold, some being fitted with very elaborate contact breaking arrangements driven by electromotors.

75. **Measurement of induction currents.**—The measurement of the electromotive force and current due to induction in the primary coil is complicated by the presence in the same circuit of the battery which drives the coil, and which exerts its own proper action upon any measuring instrument which may be put into the

circuit. The secondary coil, however, is an independent coil and the effects of induction in it can be measured, but not by an ordinary galvanometer, for if the experiment be made it will be found that connecting a secondary coil to a galvanometer produces little or no effect upon the needle. The alternate impulses from the coil tend to deflect the needle first in one direction and then in the other, with the result that the needle either remains quite still or else oscillates about its position of rest. If the magnetic needle be replaced by a small bundle of fine soft iron wires, these will be attracted by the coils of the instrument quite independently of the direction of the current in the coils, and in spite of the rapid changes of direction of the currents of a secondary coil, steady deflections of such a soft iron needle are obtained.

Mr. Giltay of Delft, Holland, has made an instrument* for use with medical coils. It depends in principle upon the attraction of a soft iron needle, which is suspended between two coils in a position at an angle of 45 degrees with their axis. When a current traverses the coils, the needle tends to set itself in the axis of the coils, and its movements are made visible by means of a scale and pointer, or else by a small mirror, as in Thomson's reflecting galvanometer.

The electromotive force of an induction coil can be best measured by an instrument invented by Lord Kelvin, and known as an electrostatic voltmeter. It is based upon the mutual attraction of two bodies oppositely electrified, and has the advantage of using no current, and therefore it measures the electromotive force of the coil on open circuit, but the capacity of the

* "Ann. der Physik und Chemie," Bd. 50, Leipzig, 1893 (figure).

voltmeter exercises a lowering effect upon the readings. When the circuit of an induction coil is closed the voltage at its terminals falls away rapidly, particularly if it be closed through a low resistance.

Reference has already been made to a coil which indicated a mean electromotive force of 89 volts on open circuit, falling to 10 volts when its poles were joined through a conductor with a resistance of 1000 ohms. This observation shows the importance of measuring the electromotive force of a medical coil under conditions resembling those under which it is to be used.

The methods of measurement just indicated give readings of the mean currents or electromotive forces, and it is not always sufficient to know this, for the effects desired may be proportional, not to the mean current, but to the maximal current, or to the suddenness of its rise or fall. This is important in medical work; for the physiological effect in giving a shock "appears to depend in great part upon the suddenness with which the maximum current strength is reached. Of two discharges which reached equal maxima, that which arrived at it in the shortest time would be the most effective in producing shocks. The value of the maximum current strength is also important."*

It follows, therefore, that it is not enough to know merely the mean current or mean electromotive force of a coil, unless the maxima can also be arrived at. When the shape of the curve of the current (see next paragraph) is regular, the maxima can be calculated from the observed magnitudes of the mean current, but

* Fleming, "The Alternate Current Transformer," vol. i., p. 180, London, 1892.

if the shape of the curve is irregular, then readings of the mean current or mean electromotive force are not a sufficient indication of the physiological effects of the currents. Giltay's instrument has, therefore, no great value for the irregular currents of a coil.

76. **Graphic representation of currents.**—The changes in value of any varying quantity, as for example, electromotive force or current, can be represented graphically by a curved line, just as the variations in the body temperature of a patient are recorded upon the temperature charts used in clinical work.

If a horizontal line be drawn to represent periods of time, and if magnitudes of electromotive force be represented by distances above the base line (positive) or below it (negative) then an electromotive force gradually rising from zero to a maximum of fifteen volts positive, and falling again could be represented by the curved line ABC, fig. 34, and the continuation of the curve CDE, represents a reversal in sign of the electromotive force, and a fall to fifteen volts negative, followed by a return to zero, the period of time of the whole cycle being represented by the base line AE. Similar curves could clearly be drawn to represent any values of a varying electromotive force or current and any periods of time.

When the shape of the curve is known the electromotive force at any instant can be readily determined by plotting out the curve, upon paper suitably ruled with lines (squared paper), and conversely curves can be constructed by observing a sufficient number of instantaneous values and marking them out on the paper and drawing a line to connect them.

The curve (fig. 34) represents the gradual rise and fall of the electromotive force from a properly con-

structed alternate current dynamo machine, and may be taken as approximating very closely to the shape of curve of an alternating system of electric light supply, and with such a curve the ratio of maximum current to mean current is as 1 to ·637, or as 1·57 to 1, if the mean be taken as unity. A curve of this kind is known as a simple periodic curve, or a sine curve, and the current from an alternating current dynamo is often spoken of as a sinusoidal current. Owing to the gradual ascent

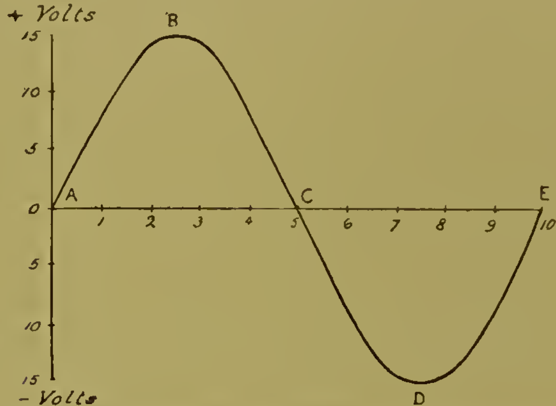


FIG. 34.—Graphic representation of a steadily varying electromotive force.

and descent of the wave, the physiological effects are somewhat different to those of currents which rise and fall more abruptly. Of late the physiological and therapeutic effects of sinusoidal currents have been studied particularly by M. D'Arsonval and MM. Gautier and Larat,* and they will be dealt with in a later paragraph.

Although the shape of the curve of the medical in-

* See "Revue internationale d'électrothérapie," 1892-93, vols. iii. and iv.; "Archives d'électricité médicale, 1893-94, vol. i.

duction coil is not fully understood, still we are not without some information upon the subject. Many curves, most of them wrong, have been drawn from time to time on theoretical grounds to represent them, but actual tracings have also been taken, one or two of which are reproduced here from a paper by Dr. Kellogg* in which the method of doing so by means of an instrument devised by d'Arsonval is fully described.

Fig. 35 shows the discharge curves of a secondary coil when the battery current was made and broken

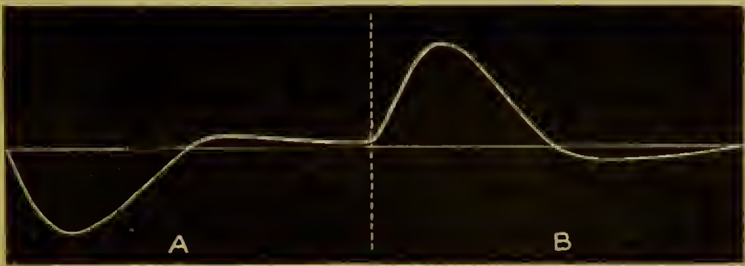


FIG. 35.—Secondary coil discharge. Battery current made and broken by hand A. Wave at make. B. At break (Dr. Kellogg).

slowly by hand. Here the wave at make is completed before the reverse current of break commences; the wave has a gradual and uniform contour both at the make and break and a pause is seen between them.

Fig. 36 shows a tracing taking with the vibrating

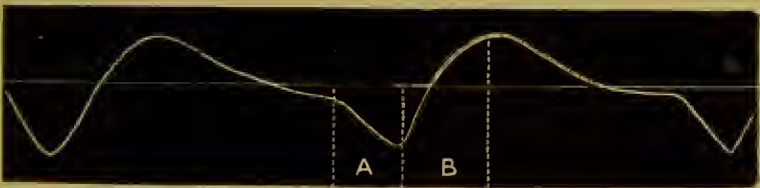


FIG. 36.—Secondary coil. Vibrator in action (Dr. Kellogg).

* "The International System of Electrotherapeutics," edited by Dr. Bigelow (F. A. Davis & Co., Philadelphia), 1894.

contact breaker in action, the make discharge commences as before, but the break discharge following too quickly after it, has altered the contour of the tracing, which now shows the break discharge as starting from the top of the wave of the make discharge, instead of from the line of zero potential. This means a reversal more or less abrupt of the direction of the current, and a greater sensation of shock.

Fig. 37, from a paper by Dr. Lewis Jones,* on the

FIG. 37.—"Make" discharges (short lines) and "break" discharges (long lines) of a coil (to be read from left to right).

duration of the discharges of the induction coil, also shows, in another way, the abrupt passage from the make to the break before the completion of the former of the two discharges.

The extent of the interference of the two waves of current depends upon the character of the contact breaker, and varies in different coils, the more rigid the spring, the more likely it is that the rebound or break will follow too quickly upon the make. The shocks of an induction coil can often be very considerably altered in character by a little adjustment of the contact screw, because changes in its position may alter the play of the spring and so make a difference in the way in which it rebounds after contact.

77. **Practical conclusions.**—The induction coil has been considered at some length in the preceding paragraphs because it is perhaps the most important

* "Electrician," London, July 21st, 1893.

electrical appliance in common medical use, and because the points which have been discussed are of value as a guide in the choice and in the use of the instrument. Taking everything into consideration, the induction coil to be preferred for medical use should be of the sledge pattern, its contact breaker should work easily an evenly, its spring should not be too rigid, its rate should be capable of variation, and its discharge curve should approximate to that of a sinusoidal wave, each discharge being given time to terminate before the commencement of the next succeeding one. There may be two different secondary coils, or else one which is tapped at several places, so that either a part or the whole of the turns may be utilised at will. With a greater number of turns the rise and fall of the current is more gradual than with a smaller number, and the painful effect or shock is lessened thereby.*

When muscle is to be stimulated through the moistened skin a lower electromotive force, a smaller number of turns and a slower rate of contact breaker may be used. When cutaneous sensory effects are desired, a large number of turns, a higher electromotive force, a rapid rate of vibration, and a dry skin, are to be preferred. The very rapid vibrator or singing rheotome has its chief use in producing a local anæsthesia in the part to which it is applied. For applications to mucous membranes the short coil is likely to prove more painful than the long coil, unless used carefully, because the mucous membrane with its low resistance may allow a large current to pass even from a coil whose electromotive force is not high. When the long

* Messrs. Waite and Bartlett, 18 Pall Mall East, supply a well made American coil with two vibrators, one slow and one rapid, which is a good instrument.

coil is used its own high self-induction will tend to protect the patient, so that the actual electromotive force applied to the body will be far below the electromotive force of the apparatus, as measured upon open circuit. The effects of the primary coil approximate very nearly to those of a short wire secondary. It has already been stated that the primary current is unidirectional, not alternating; it is probable that its discharge curve is more abrupt and peaked, and of shorter duration than that of the secondary coil, and this difference will be the more marked if the primary consist only of a comparatively few turns.

There is at present no definite evidence to show that there are any important physiological or therapeutical properties possessed by the primary current, and not possessed by a suitably wound secondary coil.

78. **Accessory apparatus.—Conducting wires.**—The conductors or leads by which the current is conveyed from the battery or other generator to the place where it is to be used, should be of insulated flexible copper wire. Copper is used because it is the best conductor among metals with the exception of silver, which indeed is not very much better and is out of the question on account of its cost. It is best to use insulated wire to avoid any risk of shocks or short circuiting from the wires coming into accidental contact with one another. Suitable wires may be bought insulated either with cotton or silk or india-rubber, and for cases where the current has to be conveyed some little distance it may be convenient to use double conductors made of two insulated wires twisted together. In this case it is well to mark the ends, so that there may be no difficulty in recognizing the positive and negative wires. A pole-tester, § 62, will prove useful

for this purpose. It is useful to have the two conductors covered in two different colours, say red and green, as it makes it more easy to distinguish between them, in tracing their attachments to the battery or to the electrodes. A convenient length is four and a half or five feet. Suitable cords with ends to fit the battery terminals are sold by the instrument makers. It is important to know that the wire core of these covered cords may become broken inside the covering, and give trouble if not discovered, the commonest breaking point being near the ends. Faulty connections are one of the commonest causes tending to throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination, yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of the instrument maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar with the proper management of it, in order to avoid the expense and annoyance of perpetually putting it into the hands of an instrument maker.

As a matter of fact with moderate care no difficulty need occur from faulty contacts. It is advisable for the sake of neatness, to use but one form of binding screw as far as possible. There are of course many forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument maker's stock.

79. **Electrodes.**—The terminals by which the current is applied to the place where it is to be used are called electrodes. The word electrode is also used to describe the terminals by which the current leaves the battery or enters any instrument. The special terminals used in medical treatment are sometimes called

rheophores, a term which has also been applied to the conducting wires, and here we may once for all protest against the use of so many unnecessary terms. Such words as rheophores for electrodes or conducting wires, rheostats or rheochords for resistances or resistance coils, rheotropes for commutators, and rheotomes for contact breakers, are, as a rule, not wanted, and the words in common use among electricians are enough for all medical purposes. The variety in nature and shape of the electrodes used in medical practice is immense; it is necessary, however, to describe some of them. The old-fashioned brass handles and wet sponges are now almost wholly abandoned, and the favourite form of electrode at present is a disc of metal screwed into a handle and covered over with wash-leather.

The handles are of varied design, some being fitted with keys for closing the current or for opening it, or even for reversing it, one or two of these handles are figured here, and many more will be found in the instrument makers' catalogues. One handle with a key for *closing* the circuit is useful for the testing of muscles.

FIG. 38.—Handle for electrode, with key.

Care must be exercised to keep the electrodes clean, and on this account metal is better than carbon; the amadou, or flannel, or wash-leather covers, should be often renewed, and as far as possible a separate set should be kept for each patient.

Several sizes are required. Professor Erb has suggested the adoption of electrodes of standard sizes because the density of the current and the effective

resistance of the surface at the point of entry depends upon the size of the electrode, that is to say, the area from which the current passes to the patient. For different effects one may desire at one time a current diffused over a large surface of entry, and at another a current concentrated at a small surface. In the operation for the removal of superfluous hairs by electrolysis, the indifferent electrode is large and the local effects on that part of the skin which it touches are imperceptible, but the active electrode is a fine needle, and the density of the current at its point is such that strong local effects are produced where it pierces the skin even when the current is only two or three milliampères. By using standard sizes one can more readily convey to others a correct idea of the current density used in any particular case. Erb's standard sizes are the following :—

Name.	Diameter of disc.		Area of surface.	
Smallest	·5 cm.	·2 in.	·25 sq. cm.	·04 sq. in.
Small	1·3 ,,	·6 ,,	1·1 ,,	·28 ,
,,	2 ,,	·8 ,,	3·14 ,,	·5 ,,
Normal	3·5 ,,	1·4 ,,	10 ,,	1·5 ,,
Medium	5 ,,	2 ,,	20 ,,	3 ,,
Large	7·6 ,,	3 ,,	50 ,,	7·6 ,,
Very large	11·2 ,,	4·4 ,,	100 ,,	15 ,,
,,	13·3 ,,	5·25 ,,	150 ,,	23 ,,

These sizes do not cover all the variations which are required for medical practice, for in Apostoli's treatment of uterine disease the indifferent electrode is larger still, while, for nævi and epilation, electrodes made of fine sharp needles are used. An obvious objection to this series of sizes is that they are not very regular in scale, and that for the important size

of "small" electrode two alternatives are proposed. Moreover, the numbers are difficult to remember; it would be quite as useful and more convenient to adopt a series of circular electrodes numbered according to their diameters in centimetres from 1 to 10. Still another size is proposed by the same author (Erb) for use in testing the contractility of muscles, namely one of 4 cm. diameter.

For practical purposes of diagnosis and treatment it will generally suffice to have three or four sizes of disc electrode, the smallest of half an inch or one centimetre in diameter, the largest of three inches. A roller electrode and a fine wire brush are also necessary at times.

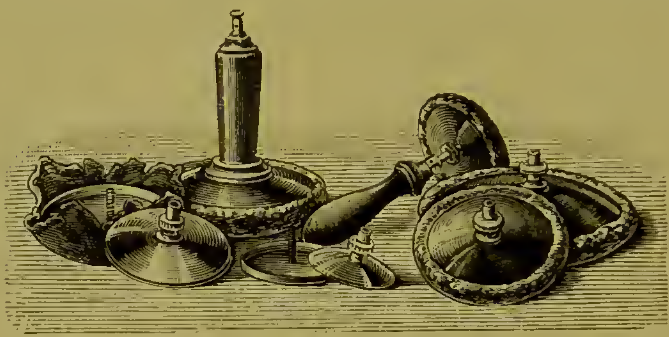


FIG. 39.—Electrodes.

A very good form of disc electrode is made, in which the operation of renewing the wash leather covering can be quickly carried out without needle and thread. The electrode is made of two cupped discs of metal, which screw together, and so hold the edges of the wash leather firmly fixed between them (see fig. 39).

The more special forms of electrode will be described and figured in the chapters which deal with the particular operations in which they are used.

In some medical applications both the poles of the battery are used equally, and in that case the electrodes at the two poles may be similar, but more often the current is applied to the affected part with one pole, which is then known as the "active electrode," and may be positive or negative according to the treatment required, the circuit being completed by the application of the

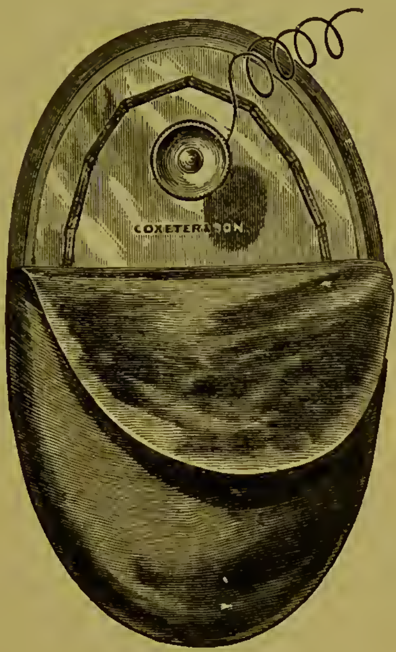


FIG. 40.—Tin electrode and sheath.

other electrode, the "indifferent electrode," to any convenient part of the body; under these circumstances the active electrode may require a handle for its proper manipulation, while the indifferent electrode is most conveniently arranged as a simple metal plate, which can be applied to the surface of the body and left there

during the treatment. It is generally an oval plate of pure tin or pewter four or five inches long. It is light and sufficiently flexible, and can be bent to fit the surface of the body. Plates of lead are not so good, nor so convenient. On one side is a binding screw for the attachment of the battery wire, and the other side is covered with a smooth piece of amadou or wash leather, which can be moistened with warm water before use. There should be a sheath or pocket with one side waterproof, to contain the electrode (fig. 40), this will serve to protect the patient's clothes from being wetted without interfering with the passage of the current. Bare metal must never be applied directly to the skin unless electrolytic effects are wished for, the current is very much more painful when it enters the skin from a metallic surface that when it first passes through a layer of moist badly conducting material. The reason for this is that the latter gives a more even contact, and most of the electrolytic action takes place in the thickness of the wet flannel or wash leather instead of in the skin.

The indifferent electrode may be slipped between the clothing and the skin, the pressure of the clothes will then suffice to keep it in place, or if the patient is lying down the electrode may be put underneath the shoulders or the hips, or it may be held against the body by the patient himself or by an attendant. In either case the operator is able to give his whole attention to the other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between. Sometimes, especially with children, it may be fastened on by a few turns of a bandage, or by a soft garter or belt of some kind. Electrodes to buckle or

clasp upon a limb are figured in the catalogues and are useful. The precaution should be taken of seeing that the proper side of the sheath and the proper face of the electrode are together, for the waterproof side will not conduct.

80. **Current collectors.**—Medical batteries for galvanic treatment are made up of a large number of cells (20, 30 or 40 arranged in series), but the number of cells to be used in different cases varies very much. On this account a quick and simple plan of altering the number of the cells included in the circuit is required so

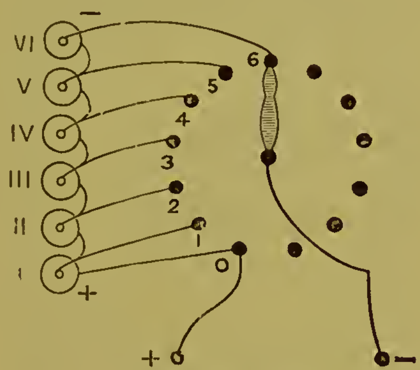


FIG. 41.—Plan of a single current collector.

that the curren. may be readily increased or diminished to suit the needs of each case by switching cells in or out of circuit. The plan is as follows:—

In the diagram, fig. 41, six cells are shown numbered I to VI, they are joined in series, and from their terminals wires are led off to seven corresponding studs numbered 0 to 6. It may be seen that a movable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding screws marked + and −, and similarly when the arm is placed on any

other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

This is in brief the principle of the current collector, as applied to medical batteries, the stud marked o being connected with one pole, say the positive pole of cell No. 1, and leading to a binding screw marked +, stud No. 1 being attached to the negative pole of the same cell and when the movable arm touches stud No. 1, the current passes along it and from there goes to the other binding screw of the battery marked as shown in the figure. Cell No. I. only is then included in the circuit; if the pointer be transferred to another stud, numbered let us say 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell or any group of cells commencing at any point, the advantage being that the cells can be used equally. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector if six cells are required not only could cells 1 to 6 be chosen but cells 4 to 9, or 7 to 12, or 13 to 18, or any other set of six. With the single collector the first cells must always provide current and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector, the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested; the double collector, however, is rather more expensive. If in the figure of the single collector (fig. 41) the wire leading from cell No. 1 to

the stud numbered 0 were not continued to the positive terminal of the battery, and if this latter were connected instead to a second arm, pivoted on the same axle, but electrically insulated from the first one and capable of independent movement (fig. 42), it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells 4, 5, and 6 only, that is to say the group of cells 4 to 6 would supply the current to the circuit. In like manner any number of consecutive

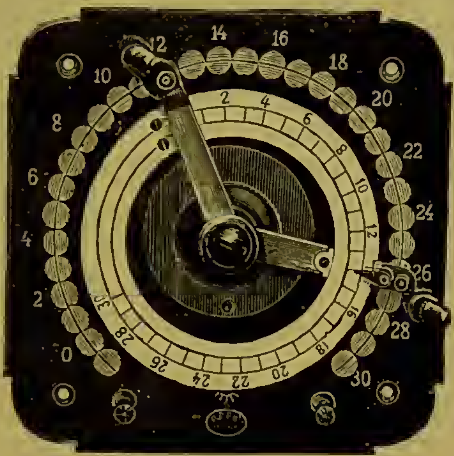


FIG. 42.—Double collector.

cells from one upwards could be picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use (fig. 42).

The studs of current collectors must be of good size, and the pointer just broad enough to touch two at once, that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the moment when the pointer moves from one stud to the next. At the same time care must be taken

that the movable pointer of any collector is not left for any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited and its energy is being ruinously wasted.*

When it is wished to test the working of a medical battery, the poles must be joined through a high resistance, for example, any of those described in § 83. With about 1000 ohms the current is reduced to a magnitude suitable for measurement with the milliampère meter; failing this the electrodes should be placed in water, some little distance intervening between them, and the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order it will indicate a regular rise of current step by step, for every cell added to the circuit. If the galvanometer needle falls to zero as the pointer is passing from one stud to the next, it indicates that the current is broken at that moment, and if a patient was in circuit he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud, it shows that the connection between that stud and the battery is faulty.

It is a bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, 1000 ohms or so, otherwise the strength of current may be so great as to damage the galvanometer, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it. If no resistance coil be at hand the plan of putting the electrodes into a little water in a saucer will usually suffice to reduce the current in the circuit to a quantity which can be mea-

* This can be prevented by the use of a collector having a divided arm, with its two portions joined through a resistance (see fig. 18).

sured in milliampères. If the battery be not fitted with a galvanometer, one must be attached for this mode of testing. It may be connected to the terminals of the battery, in series with the resistance employed.

81. **Commutator or current reverser.**—An apparatus for reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is difficult to make a satisfactory examination of the reactions of nerve and muscle without one. There are several forms in common use, but

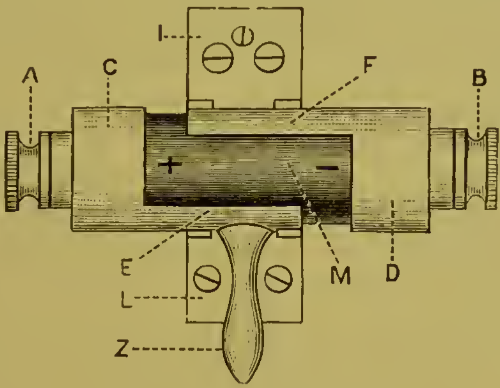


FIG. 43.—Commutator.

one only will be described (fig. 43); it was devised by Rhumkorff.

It consists of a cylinder of vulcanite M, having at each end a metal cap or ferrule C, D, and supported between two uprights in such a way as to revolve easily about an horizontal line, each end is connected to a binding screw A, B, and each metal cap is prolonged in the form of a cheek E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either side of the cylinder springing against it, are two pieces of metal I, and L, connected with the terminals of the battery.

When the cylinder is turned by means of the handle Z, either of the metal cheeks can be brought into contact with each of the springs I, L. The positive pole of the battery connected say with L, can thus be brought into connection with either the binding screw at A, or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and – signs on the vulcanite cylinder indicate the polarity of the binding screws; in the position shown A is positive, a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder, which then comes into view, will have the + and – signs transposed also.

82. **Regulation of current.**—When the current is regulated by the method described in § 80, it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient to regulate by this method. As for example, in regulating the current from the electric light mains, where the electromotive force is maintained at a constant figure. In general, with batteries, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a circuit has a total resistance of 3000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of six milliampères; if now it is required to double the current it is easily done by adding twelve more cells,

taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit it would be necessary in order to double the current, to take out a resistance of 1500 ohms, which might be impracticable. When it is desired to increase current by taking out resistances, it is of course requisite that the resistances to be removed must first be connected up in the circuit before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a cautery burner whose resistance with its leads amount to ·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance ·002 ohm; the current would be well governed by having a variable resistance up to ·5 ohm in the circuit. When the current was turned on with full resistance it would amount to about 3·9 ampères, and by reducing the variable resistance to ·088 ohm a current of 20 ampères would be given which would probably suffice to heat the burner.

83. **Resistances.**—Resistances or rheostats* are made up in many forms to suit the purposes for which they are required, and the currents they have to carry. Fig. 45 shows an arrangement of standard coils for measuring purposes, to form a "resistance box." The coils are generally made of a length of insulated German silver wire doubled on itself, fig. 44 (that the coils should have no self induction) and coiled on a bobbin. Coils are then arranged in the following

* The word "rheostat" is perhaps the least objectionable of those referred to in § 79, solely, however, because it has been hallowed by use.

order:—1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1000, 2000, 2000, 5000 ohms respectively, so that any of them can be thrown in or out of circuit by removing or replacing plugs on the top of the resistance box. It will be seen that with the above arrangement of coils any

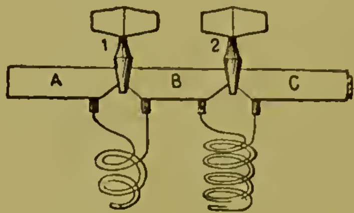


FIG. 44.—Plan of Resistance Coils.

resistance from 1 to 10000 ohms can be put into circuit. Such resistance boxes are capable of the very highest accuracy, but as a rule this is not required in medical work, and they are damaged if any large current is sent through them, besides which they are exceedingly

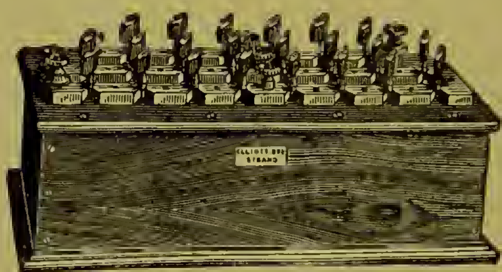


FIG. 45.—Resistance Box.

costly. They are necessary for scientific investigations, or where it may be necessary to find resistances of apparatus or the electromotive force of batteries with high accuracy.

For medical treatment it is more important to have a

resistance which can be smoothly adjusted and varied while the current is passing, than one which is graduated exactly in ohms.

An useful form of adjustable resistance is shown in fig. 46, where a movable arm is made to touch successively upon a series of metal studs, the amount of resistance thereby interposed being shown by figures marked opposite the studs.

A form of resistance coil that will frequently be found useful is one which is known as the "wire rheostat." It is very convenient in cases such as the

FIG. 46.—Adjustable resistance for medical use.

example given above, in which there is a small external resistance only in the circuit, and a large current is to be regulated. It usually consists of a long open corkscrew coil or helix of moderately thick uncovered German silver or other wire, such as platinum silver alloy, of high specific resistance. The current is led in at one end of the helix and a metal sliding piece which can pass from end to end of the coil forms the other terminal. The resistance interposed is easily seen to be proportional to the number of turns of the helix between the end attached to the terminal and the sliding piece

The form of this resistance is favourable to cooling, thus a much larger current may be driven through it than through a coil of covered wire not open to the air. It is especially useful for regulating the current in cautery or lamp instruments (see Chap. XV.).

84. **Water rheostat.**—Another adjustable resistance apparatus made up in many forms is the "liquid

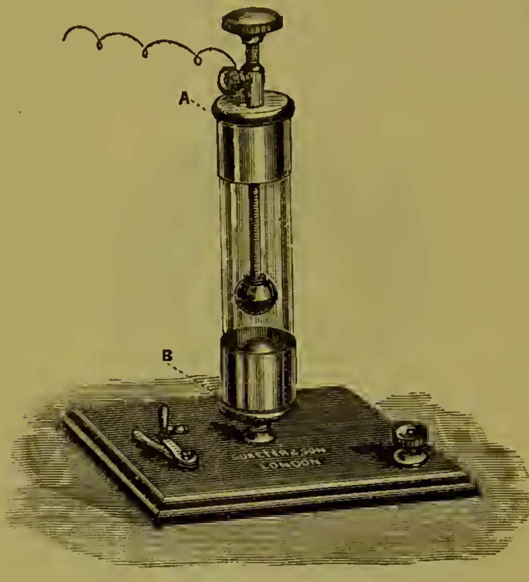


FIG. 47.—Water rheostat.

rheostat." It consists of a glass vessel, watertight and filled with water or some saline solution, it terminates below in a metal foot B and binding screw, and a metallic rod having a screw passes in from above through a collar A, and this carries the other binding screw. When the rod is screwed quite down it touches the base of the tube, and the circuit is completed

through the metallic contact; when it is raised the current must pass through the badly conducting liquid. The resistance offered by the liquid varies with the length of liquid to be traversed and the nature of the solution, and the rod can be roughly graduated for the resistance of the liquid to be used. In a modification

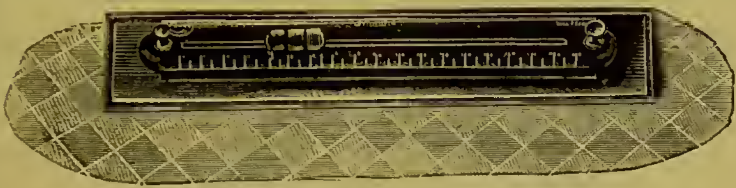


FIG. 48.—Graphite rheostat.

of this instrument a damp sponge takes the place of the liquid; the resistance varies with the pressure upon the sponge, which is regulated by turning a screw as before.

85. **Graphite rheostat.**—A very handy form of adjustable rheostat for high resistances and small currents

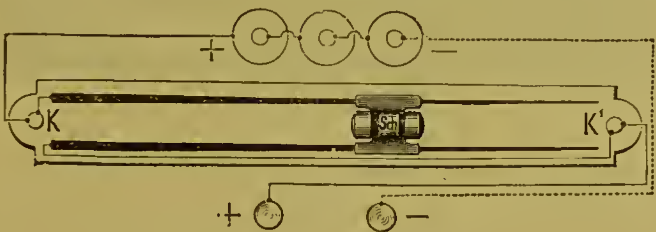


FIG. 49.—Plan of graphite rheostat.

is a sliding graphite resistance, figs. 48 and 49. It consists of two parallel pencils of graphite, with a metal sliding piece moving between them, and in contact with both. As the position of the slide is altered, a greater or less length of the badly conducting graphite is brought in the circuit and the resistance of the circuit is

varied thereby. Graphite rheostats are also made up in various patterns.

It must be borne in mind that a resistance, suitable for regulating small currents, may be burnt and destroyed if large currents are allowed to traverse it, also that a resistance of one or two ohms may be ample for regulating a lamp or cautery, but will exercise no appreciable regulating effect upon a circuit of high resistance. In general a rheostat should have a resist-

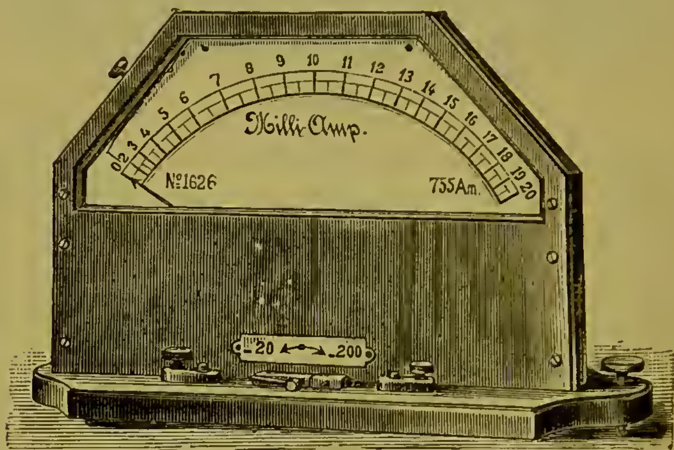


FIG. 50.—Vertical galvanometer.

ance approximately equal to that of the circuit which it is to control.

86. **Galvanometers.**—It is generally of the utmost importance that the medical man shall be able during the course of an electrical operation to see at a glance what current is passing, and for this purpose a galvanometer is necessary. We may refer the student back to § 27 for a cursory account of the theory of the galvanometer. Here we have to describe one or two that are in common use.

Galvanometers for medical use should always be calibrated and marked by the makers to read in milliampères.

A galvanometer calibrated to read milliampères may be called a "milliampèremeter" just as one calibrated to read ampères is called an ammeter. Medical men owe it to Dr. De Watteville that the milliampère has been chosen to be the standard for medical purposes and for this it is a most convenient measure.

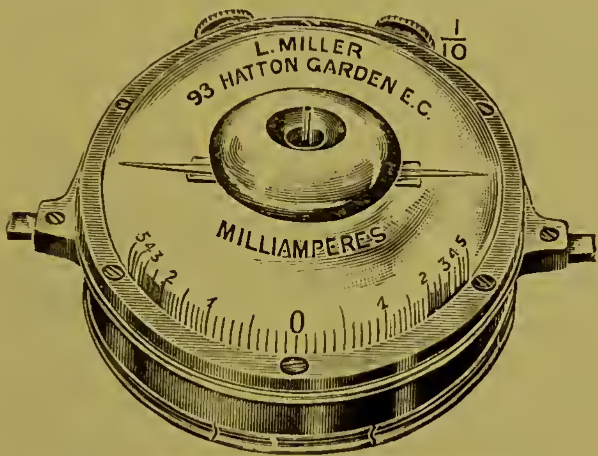


FIG. 51.—Horizontal galvanometer with floating needle.

Medical galvanometers may be conveniently divided into the vertical and horizontal forms. Fig. 50 shews one of the vertical type. They are easy to read, but after a time they cease to give correct readings and indicate too low a figure. They are convenient in use, however, because it is not necessary to set them in a definite position with regard to the north and south line (magnetic meridian) of the place where they are to be used.

Fig. 51 shews a form of horizontal galvanometer

which is very well suited for medical work. The needle floats in liquid, and therefore moves very readily. Its movements are "damped" by the liquid, which makes it nearly "dead beat," thus saving time, and there is no pivot to wear out. It can easily be disconnected, and so can be used with several different batteries. They are fitted either with one shunt or with two, if large currents are to be used.

Before use all horizontal galvanometers must be so placed and levelled, that the needle comes to rest at the zero, and swings freely about that point. The magnetic needle then points along the magnetic meridian of the place where it is to be used.

Fig. 52 is a representation of Edelmann's large non-portable galvanometer which is very convenient as a standard instrument. At F is seen one of the three feet of the instrument with its levelling screw; M is the base board, G a short cylinder of glass covered by a glass top, L which is perforated at the centre for the needle suspension to pass through; these make a case for the instrument and keep it from dust. The magnet with its long straw pointer Z, the end of which is seen at W, is suspended by a cocoon silk fibre supported from a pin, which can be raised and lowered by a rack and pinion worked by the milled head S, N is a wooden ring which supports the pillar down which the suspension passes. T is the scale, a cylinder of paper divided to read in milliampères. This arrangement of the scale is specially designed in order that the instruments may be read from a distance. At *a* and *b* are seen the wires which lead the current into and out of the galvanometer, the three small discs numbered in the figure 10, 20 and 30, should be numbered 10, 100, 1000, they are the heads of three screws by means of which shunts

can be thrown in to reduce the proportion of current passing through the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1000}$, respectively of that in the whole circuit, so that when one of these is in use the reading of the scale must

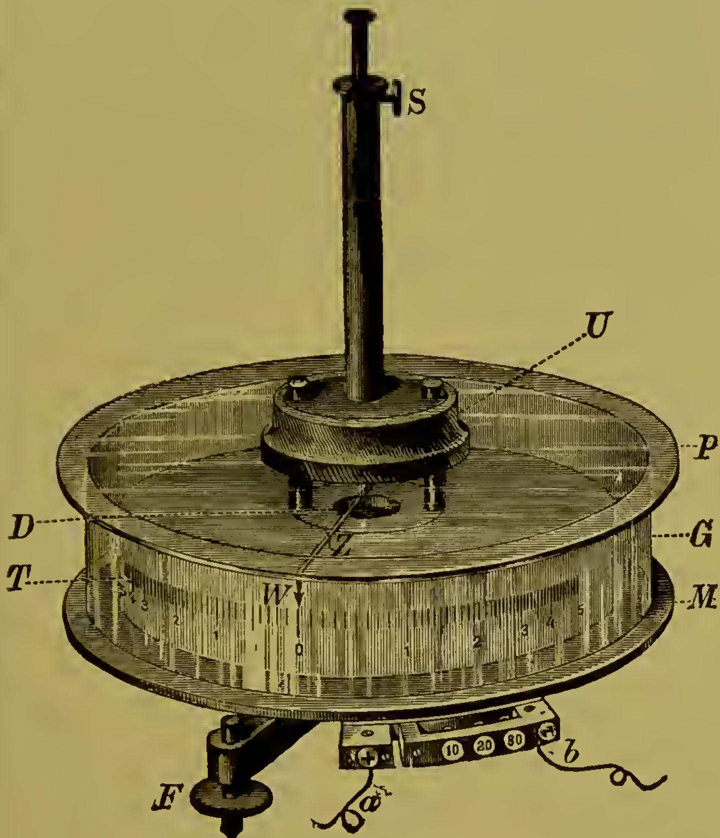


FIG. 52.—Edelmann's galvanometer.

be multiplied by 10, 100 or 1000, as the case may be, to give the whole current in the circuit. In this way the instrument is enabled to give readings over a much wider range than would otherwise be possible.

The arrangement of the shunt circuits is illustrated in

figure 53. Between the binding screws marked + and – the galvanometer coils are represented. Two other paths are shown beneath, either of which can be completed at the points of their respective screws; both of them have a lower resistance than the circuit of the galvanometer coils and when closed they convey nine-tenths and ninety-nine hundredths respectively of the current, while the remaining tenth part or hundredth part traverses the galvanometer coils and produces its proper deflection. But if the deflection is known to be

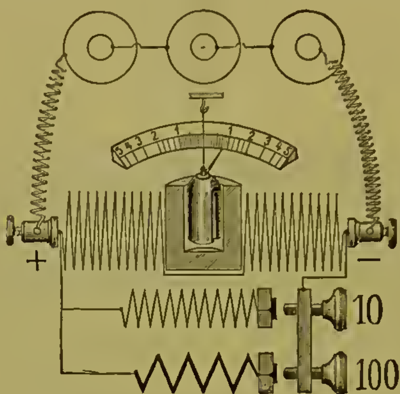


Fig. 53.—Plan of shunt circuits of a galvanometer.

due to one-tenth of the current only, then to get the total current the indicated reading must be multiplied by ten, and the same for the other or 100 times shunt.

Both shunt circuits are not to be closed at one time.

By means of a battery and a resistance box it is easy to verify the readings of a galvanometer and to determine whether the shunts work properly and correctly.

In another form of galvanometer, sometimes known as the D'Arsonval type, the movements of the needle are controlled by placing it in a strong magnetic field

between the poles of a horse-shoe magnet; this has the effect of making the movement of the needle very "dead beat," that is to say it takes up its position without oscillating to and fro, and so when current is being measured time is saved; on this account they are much in favour for certain purposes, but it is necessary to recalibrate them from time to time, for the value of their indicated deflections tends to alter as the strength of the controlling magnet diminishes with the lapse of time.

Vertical galvanometers in which the position of the needle depends partly upon gravity, and partly on the magnetic strength of the needle, are also liable to read too low as the needle gradually loses its magnetism.

Horizontal galvanometers of the type figured above, figures 51, 52, are free from these objections; in these the position which the needle takes up is the resultant of two forces, viz., the attraction of the earth's magnetism tending to hold the needle in the magnetic meridian, and the attraction of the field of force of the coils tending to draw it into a position at right angles to this. Changes in the magnetism of the needle do not alter the relation which the two opposing pulls bear to one another, and therefore the deflections of the needle are not altered if the magnetism of the needle becomes diminished.

87. **Ammeters and Voltmeters.**—Galvanometers which are calibrated and marked to give readings direct in ampères or in volts are called by the above names. They assume many forms, and are specially wound to suit the currents or voltages they are to indicate. In medical practice it is not often required to measure currents of a magnitude of several ampères unless one wishes to know the strength of current

needed for lamps or cauteries. In general an ammeter has a very low resistance, and must not be coupled direct to the terminals of an accumulator or to the main supply without some instrument or other resistance in the circuit to protect it from being overheated.

Voltmeters on the other hand generally have a high resistance. The most convenient way of measuring the electromotive force of a medical battery is to use its own galvanometer, and by a simple calculation from Ohm's law the voltage of the cells can be calculated as follows:—

Supposing the resistance of the galvanometer to be 25 ohms, and a resistance coil of 975 ohms be connected to the terminals of the battery; the total resistance in circuit will be 1000 ohms.

Now one volt acting upon a resistance of one thousand ohms will cause a current of one-thousandth of an ampère to flow, that is to say one milliampère. With five volts, five milliampères and so on. The readings of the galvanometer in milliampères will therefore express the electromotive force of the cells in volts if the resistance of the circuit amount to one thousand ohms; the slight correction for internal resistance of the cells may be disregarded. This method has the advantage of measuring the electromotive force under conditions like those for which the battery is to be used.

Instrument makers supply, if required, a resistance coil properly wound to bring up the total resistance of the galvanometer circuit to a thousand ohms, in order to simplify this mode of measuring the electromotive force of the cells of a medical battery. With this it is very easy to test the voltage of the individual cells by taking readings of the galvanometer while switching on the cells one after another. Each cell may be taken

separately if the battery have a double collector, § 80; if it have a single collector, the increase of reading for each cell added may be taken to represent its electromotive force.

There are many other types of voltmeter for other purposes. Cardew's consists of a long and fine platinum iridium wire which is heated by the current, and expands, moving a pointer which indicates the expansion on a specially calibrated dial. Ayrton and Perry's is a coil or solenoid, which draws a soft iron core into it, and the movement is indicated on the dial by a very ingenious spring invented by them. The electrostatic voltmeter is an adaptation of the principle of the mutual attraction of oppositely charged bodies. It uses no current, and will read equally well on either continuous or alternating circuits above fifty volts, as also does Cardew's. All these instruments are calibrated by the makers to read in volts, but should be checked from time to time by a competent person.

88. **Voltameters.**—The periodical testing of a galvanometer is best carried out by comparing it with a standard instrument or else by means of a voltameter. The latter method is an electrolytic one; and consists in passing a current through the galvanometer and an electrolyte for a measured time; and determining the amount of chemical decomposition which has been produced, § 37, from this, the current can be calculated and compared with the readings given by the galvanometer.

In the water voltameter the products of electrolysis are the gases Oxygen and Hydrogen, and these are collected and measured in some conveniently designed apparatus. Ten milliampères of current will liberate 1·056 cubic centimetres of mixed gases in ten minutes.

The electro-deposition of metallic silver or copper from their solutions, may also be used for voltametric purposes by weighing the metal deposited after a measured period of time. See Ayrton, "Practical Electricity," Chap. I. and VIII.

89. **Practical note.**—In concluding this short account we would remind the reader that there are few things so difficult to follow in all their vagaries as the connections of electrical apparatus. Probably at first he will find considerable difficulty in making the simplest piece of apparatus work. But he need not, therefore, jump to the conclusion that the battery or galvanometer or instrument that he is using is out of order, and that the instrument maker need be sent for to put it right. The connections should first be examined and in all probability the fault will be found there. It is a very good thing to draw a diagrammatic plan of these and so check them off and make certain that all wires are connected up in the intended way. It is of course understood that the values of the various electromotive forces and resistances in the circuit have been so arranged as to give the required effect. If things will not go right then, the resistances and electromotive forces of the batteries should be taken, and it will be quite time enough to apply to the instrument maker when something has been found to be wrong with these. A little intelligence in the application of theory will often save much cost and trouble in practice.

CHAPTER VI.

ELECTRICITY OF HIGH POTENTIAL. STATICAL ELECTRICITY.

Historical. Description of instruments. The Holtz machine. Wimshurst's machine. Conductors and electrodes. Treatment by charging. The static breeze. Treatment by sparks. The Leyden jar. Static induction. Effects of static treatment. High frequency and high potentials. D'Arsonval's experiments. Their physiological and therapeutic effects.

90. **Introductory.**—In comparing the so-called Electrostatic or Statical methods with other kinds of electrical treatment, it is found that an important feature of the former is, that very high electrical potentials even up to a hundred thousand volts or more are employed.

These enormous voltages can usually be applied to patients without danger, because of the small capacity (§ 18) of the machines commonly employed for producing them. The actual current in the discharge from an electrical machine is very small. Any rise in the capacity of the apparatus is accompanied by an increase in the magnitude of the discharge and in the sensation of shock, thus machines with large prime conductors, or those which have their capacity greatly augmented by Leyden jars (§ 20) may give shocks which are severe or even dangerous.

91. **Description of instruments.**—The first form of electrical machine was a large sulphur ball which was excited by one hand as it was revolved by the

other. It was made by Otto von Guericke of Magdeburg in 1672. Some interesting reproductions of old figures of early electrical machines are given by Dr. Mount Bleyer, of New York, in Bigelow's "System of Electro-Therapeutics." Subsequently resin was used and then a glass cylinder instead of the sulphur ball. In 1740 Winckler excited the glass by means of horse-hair cushions covered with silk instead of the hands.

In 1760, Ramsden substituted a circular glass plate for the cylinder, and his apparatus was until recently in common use. In Ramsden's machine electrical separation is produced by the friction of the glass disc between two sets of cushions.

In most modern machines induction is utilized for producing the electrical separation, and on this account they are often known as influence or induction machines. In 1865, Holtz of Berlin invented a machine which, when charged from an electrophorus would continue to produce electrical separation by induction. This form of machine proved to be far superior to the older frictional machines, and quickly supplanted them in spite of certain drawbacks. In its original form the cutting of its plates presented difficulties, it required to be excited from a separate machine or electrophorus before it would begin to work, it was liable to lose its excitation if worked upon open circuit, and it had a tendency to reverse its polarity during action. From its good qualities it has been made the object of much work in the hope of remedying its defects, and it has been brought to a high degree of perfection by the instrument makers of the United States where the Holtz machine is in almost universal use for electro-therapeutics.

92. **The Holtz machine.**—In its simplest form it consists of two plates of glass, A, B, one having a

diameter slightly greater than the other. The larger plate is fixed, but the smaller one is made to rotate by means of a cord and pulley, its axle passing through a

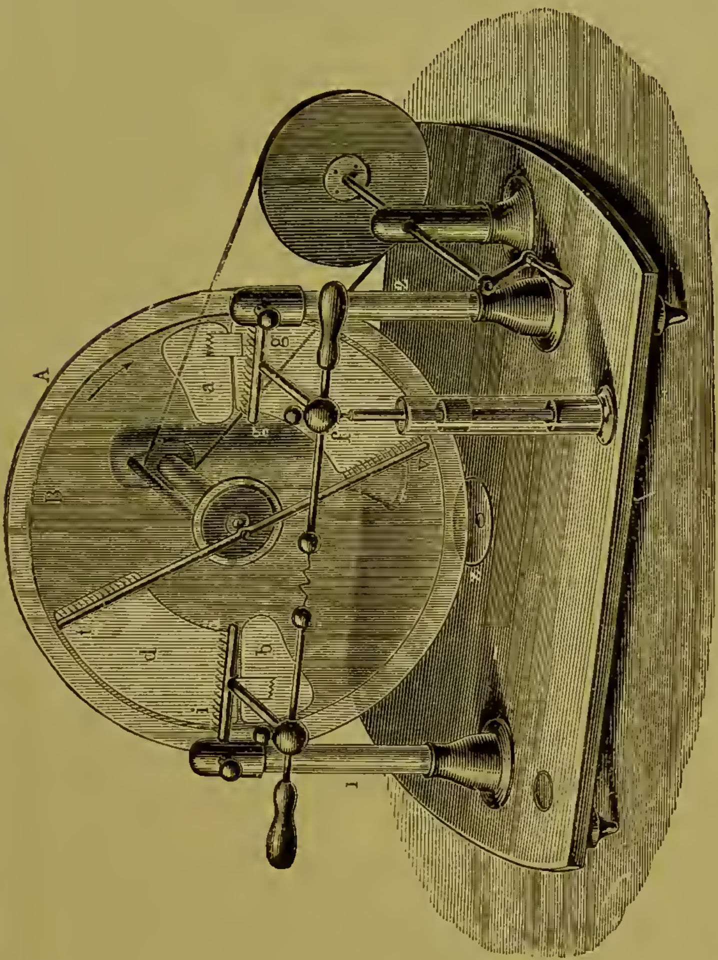


Fig. 54.—Holtz machine.

hole in the centre of the larger plate. The plates are quite close together but do not touch. In the fixed plate are two windows, *a*, *b*, diametrically opposite to each other. Two pieces of paper called "field plates"

are glued on to the fixed plate, one above the window on the left side and one below the window on the right. They are on the surface of the plate away from the revolving one. A tongue from each of these pieces of paper, protrudes through each aperture and nearly touches the revolving plate. The plate is rotated in an opposite direction to that in which the tongues point. Near the outside of the revolving plate are two brass combs, *g*, *i*, supported by two brass rods with knobs, *f*, forming the prime conductor. Two smaller brass rods, with ebonite handles, and two small brass balls act as electrodes and slide through the knobs at their other ends. These smaller balls can be approximated and withdrawn from each other by means of the handles and in that way the length of spark can be regulated. The rod *t v* is called the neutralising rod and is said to make the machine less likely to reverse. Before starting the machine one of the field plates must be charged from an electrophorus. The knobs of the discharging rods are to be brought together. The moveable plate is then rotated rapidly and sparks will pass between the electrodes when they are separated.

In the modern machines used in electro-therapeutics there are many modifications in details. First the machine has four, six or eight pairs of plates and is enclosed in an air-tight case. The fixed plates instead of being round, with windows and a hole for the axle are oblong and are held in place by grooves in the framework of the case, and each is made in two pieces which do not quite touch each other and so leave room for the axle to revolve between them. The "field plates" of paper are glued to the fixed plates on the side which faces the rotating plate or near side, instead of being on the opposite or far side. This prevents the

reversals of polarity during action which occurred with the original Holtz machine, by preventing the formation of an accumulated charge of opposite sign on the near side of the fixed plate, as used to be the case when the field plate was attached on the far side.

The machines for electro-therapeutics from the United States usually have revolving plates thirty inches in diameter; the case is of glass with a stout framework of wood which carries the axle, and is pierced for the prime conductors. These are insulated by thick rods of ebonite where they come through the side of the case, and terminate in large knobs fitted with sliding discharging rods. The machine is driven by a belt and pulley, either by hand or by an electric or other motor. For providing the initial charge which is required to excite the action of the machine a small Wimshurst machine is fitted in the corner of the case with gearing by means of which it can be started and stopped as required.

93. **The Wimshurst machine.**—The Wimshurst machine has the advantage over the Holtz that it is self exciting, and its polarity will not reverse under ordinary circumstances while it is in action. It consists of two circular glass discs (or any even number up to twelve), mounted in pairs upon a fixed horizontal spindle in such a way that they rotate in opposite directions at a distance apart of not more than one-eighth of an inch. Each disc is attached to the end of a hollow boss of wood, or of metal, upon which is turned a small pulley. The pulleys are driven by a cord or belt from larger pulleys attached to a spindle below the machine, and rotated by a winch handle or by a motor, the difference in the direction of rotation of the discs being obtained by crossing the alternate belts.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil or thin brass disposed around the discs at equal angular distances. These sectors are not essential to the action of the machine, but they make it more easily self exciting. With large machines and carefully adjusted neutralising rods (see next paragraph)

FIG. 55.—Wimshurst machine.

the presence of sectors is of no advantage, for such large machines excite quite readily without sectors.

Twice in each revolution the two sectors situated on the same diameter of each disc are momentarily placed in metallic connection with one another by a pair of fine wire brushes attached to the ends of a curved rod, called the neutralising rod, supported at the middle of its length by one of the projecting ends of the fixed

spindle upon which the discs rotate, the sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle; and there is one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 75° from the collecting combs, and 30° from one another.

The fixed conductors consist of two forks furnished with collecting combs directed towards one another, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the disc. To these fixed conductors are attached the terminal electrodes, whose distance apart can be varied. Leyden jars are usually fitted to the machine by the makers, but these must admit of their outer coatings being disconnected, before the machine is used for treating patients, see § 106.

The machine is very efficient and perfectly self exciting, provided there are sufficient sectors, generally requiring neither friction nor any outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary conditions the machine works at its full power after the second or third revolution of the handle. It has been suggested that this initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it.

When the glass plates are very large they are apt to split. On this account a modification of the Wimshurst

machine has been made with ebonite plates, which are said to be superior to glass, and are not liable to break-

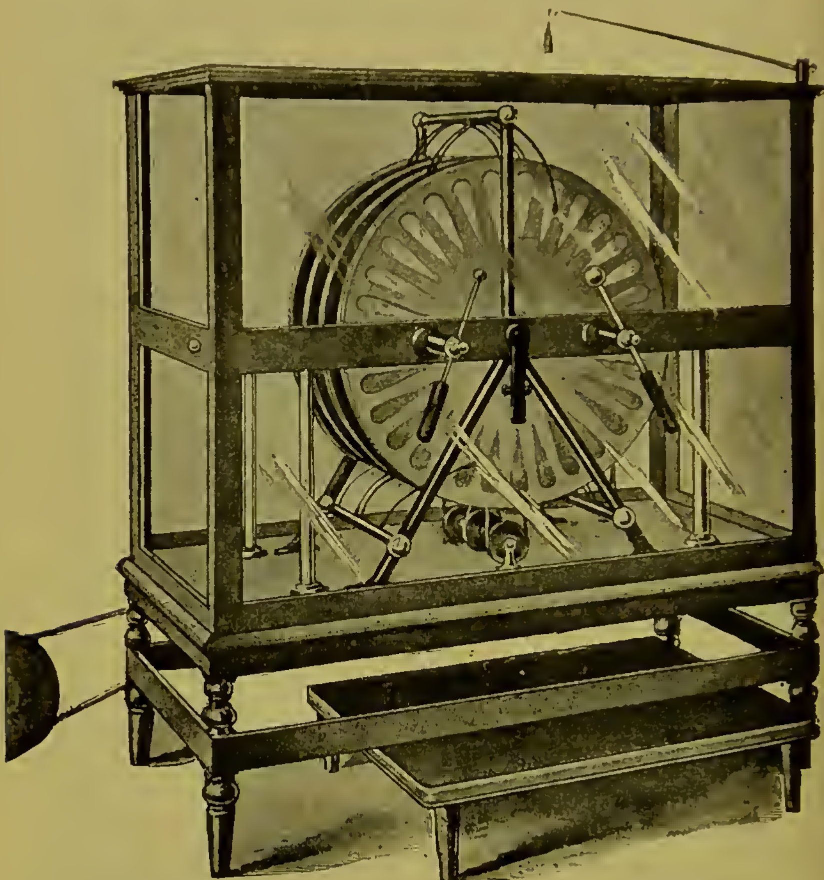


FIG. 56.—Large Wimshurst machine or medical use, with platform, and electrode for head breeze.

age during transit or use and can be safely driven at a very high speed. There is, however, a grave objection to the use of ebonite, as it gradually deteriorates on the

surface and loses its insulating properties; moreover, the plates of ebonite cannot be kept true, but bend and buckle, glass is therefore the best.

Mr. Pidgeon has introduced modifications into the Wimshurst influence machine by adding fixed inductors to reinforce the action taking place between the plates, by increasing the size of the tin-foil sectors, and by very carefully insulating the sectors from leakage to each other, and in this way he has succeeded in increasing, very notably, the output of a machine of a given size as compared with the output of an unmodified machine having plates of the same dimensions.

A Wimshurst machine for therapeutic work should have eight plates of thirty or thirty-six inches diameter. The figure shows one constructed for my own use by my friend Mr. C. L. Schwind. This machine, without any Leyden jars, gives streams of sparks of from nine to ten inches long, and serves admirably for all therapeutic purposes. It is enclosed in a roomy case to prevent waste by leakage from the machine to the case, and to protect it from damp and from dust. It runs silently and smoothly and has not failed on any occasion. It is driven by a $\frac{1}{4}$-horse electric motor.

94. **Medical applications.**—Whether the Wimshurst or the Holtz machine be adopted the essentials are the same, namely the machine must be large enough, it must be built to stand hard work and it must be enclosed in an air-tight case. The effects which large statical machines can produce are almost startling to those who have been familiar only with the phenomena produced by small machines, and the therapeutic results of their use are obtained so easily and so promptly that it is a pleasure to use them. The progress with Statical treatment in the last few years is

due entirely to the work done by medical men in the United States. With characteristic enterprise they

FIG. 57.—The American Holtz machine, medical type. (Waite & Bartlett Manf. Co., New York).

have elaborated the Holtz machine and taken up the use of it so effectually that there are now in New York alone three firms making and selling Holtz machines in

large numbers while one of these firms has just recently become established in London.

In the summer of 1898 I had the pleasure of making the acquaintance of Dr. Monell of Brooklyn, the author of a large and admirable work called, "A Manual of Statical Electricity in X Ray and Therapeutic Uses." He very kindly procured for me from New York a set of

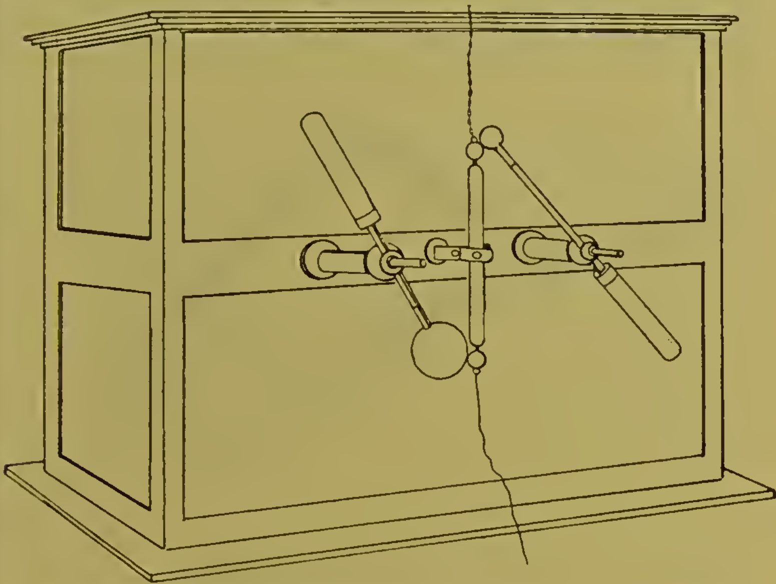


FIG. 58.—Front of case, showing ebonite rod with connections to earth above and to platform below, and arrangement of poles.

electrodes and apparatus for use with the static machine and delayed his departure from London until they arrived in order to give me a full practical demonstration upon the modes of application which he had elaborated and was teaching in the Brooklyn Post Graduate School of Electro-Therapeutics. So attractive was the field of work which his lessons revealed that I at once arranged to have a new Wimshurst

machine built, with eight thirty-six inch plates to take the place of the one with four plates which I then had, and for what follows in this chapter I desire to make grateful acknowledgment to the instructions of Dr. Monell, both, as communicated personally and from the pages of his book, which is indispensable to any worker with the static machine.

In the methods of treatment advocated by Dr. Monell, the patient is usually insulated upon a platform with

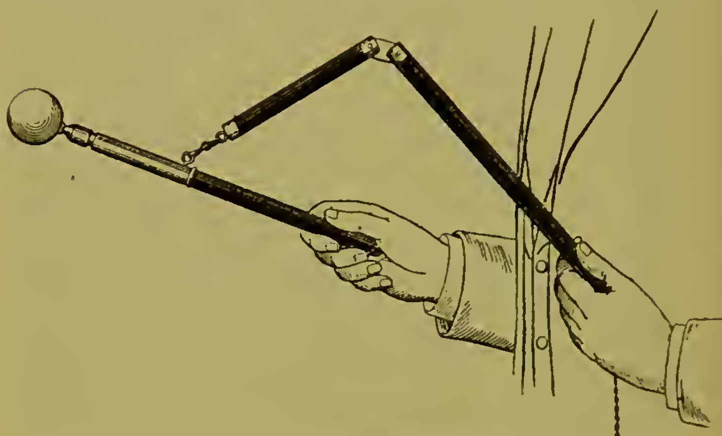


FIG. 59.—Dr Monell's electrode holder.

glass legs, and is connected to one pole of the machine by a conductor; the electrodes, whether knob, or point, or roller, are connected to earth, and the second pole of the machine is also earthed. The advantage of this mode of procedure, which is rendered possible by the power of modern machines, is that the instruments handled by the operator are at zero potential, and he therefore is not called upon to use any insulating device to protect himself from shocks. The earthing of the electrodes is arranged by a long light chain

connected at one end to a gas or water pipe in the building, and fitted at the other end with a handle shaped like a flail to which the electrodes are hung. This handle, or "electrode holder," of Dr. Monell is an ingenious contrivance, and serves to support the weight of the electrodes during their application. It is held in the left hand close to the body, and supports the weight of the electrodes somewhat as a crane supports a weight. Thus the right hand is used to hold and direct the electrode, while the left hand supports the weight of it and so relieves the right arm.

A solid ebonite rod with brass terminal knobs is held in a wooden clamp between the dischargers of the machine (fig. 58). The upper knob is for the earth connection, the lower is for the connection to the platform. In this way either pole of the machine can be put to earth while the other is connected to the platform.

95. **Accessory apparatus.**—The accessories which are essential for the proper use of a static machine are as follows:—A platform with glass legs, chains for earthing conductors, a single point electrode, a multiple point electrode, a brass ball electrode, a brass roller, and a Monell's handle for holding these; also, a swinging brass rod carrying a wire tassel which is best attached to the case of the machine as shown in fig. 56. A brass adjustable stand to hold a fixed electrode, a sheet of brass for a footplate, and a connecting rod or wire to connect the patient, or the platform, to the machine. There are other electrodes for more special uses, and it may be of advantage to have Leyden jars arranged for use in certain cases. Their applications will be considered in a later paragraph.

Hitherto the demand in Great Britain for static machines adapted to medical purposes has been nil.

It has therefore been necessary for me to have all the parts and fittings for the work made to order after my own instructions, and it may therefore be useful to others if I give the addresses of those who have made them for me in case others may want similar things. Thus the Wimshurst machine figured above is made by Mr. Lionel Schwind, of Broomfield near Derby, and cost £42; the case for the machine and the platform are by Messrs. Allard and Co., of New Street, Bishopgate, costing from £18 to £30 according to the style and finish of the workmanship. The prime conductors and dischargers by Mr. L. Miller, of 93 Hatton Garden. The electrodes I had from Messrs. Van Houten and Ten Broeck, of 300 Fourth Avenue, New York, who also can supply glass legs cast with a screw thread at their upper ends for convenience in fitting; they supply the outfit of electrodes for £10. The establishment by Messrs. Waite and Bartlett, of New York, of a branch house in London at 18 Pall Mall East, will enable medical men in this country to provide themselves with a complete outfit with a Holtz machine without trouble and delay, and Messrs. Watson and Sons, of High Holborn, are prepared to supply an outfit resembling my own with a Wimshurst machine and all accessories complete. It is likely that the advantages of statical treatment may gradually become recognised in this country, particularly, now that the same machine will also serve for X ray work.

96. **The insulated platform.**—This is a most important part of the outfit. A bad platform may reduce the efficiency of the treatment by one half through losses of charge from leakage. To reduce these losses as far as possible the platform must be made with all corners and edges carefully rounded off and made

smooth, the glass legs should be at least ten inches long and twelve inches is even better. There should be a rounded beading or edging to the platform to prevent the chair or stool from slipping off through any movements of the patient. The dimensions recommended by Monell are forty-two inches by twenty-seven. The

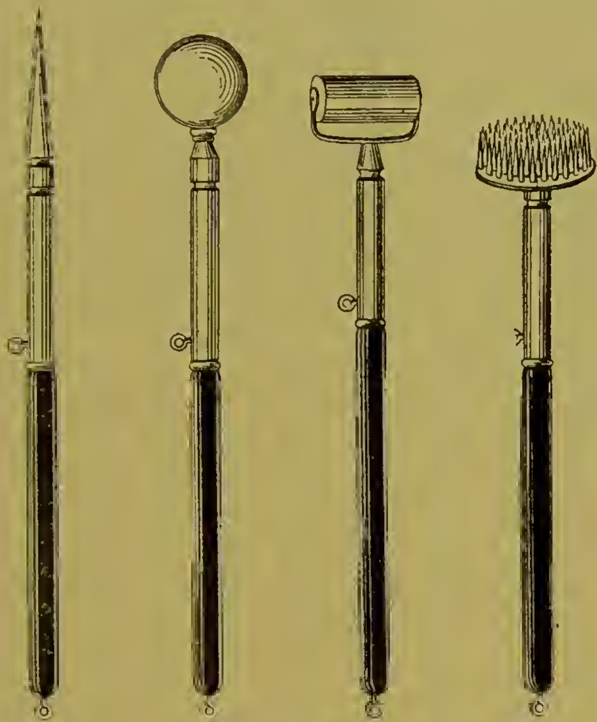


FIG. 60.—Electrodes.

platform and the glass legs must be strong enough to support the weight of the heaviest patient. Owing to the size of the platform it is useful that the case of the machine shall be so built as to permit of the platform being pushed underneath it when not in use, otherwise the platform takes up a great deal of floor space.

97. **Electrodes.**—Fig. 60 shows the four chief elec-

Fig. 61.—Stand electrode.

trodes, namely the single point, the multiple point, the knob or ball electrode and the roller. The eye at the side of the electrodes is for attachment to the Monell handle, while the eye at the ends is for hanging up the electrodes upon hooks when they are not in use. Fig. 61 shows a stand with combined ball and point electrode; it is useful in certain applications, the stand is hinged at the top and can be raised and lowered to bring either the knob or the point into any desired position.

The single point electrode is used for giving the static breeze, and the multiple point is for the same purpose, its effect being rather stronger. The ball electrode is three inches in diameter and is used for administering sparks. The roller also gives spark discharges but in a special way. It is used by rolling it over the surface (clothed) of the patient. When this is done showers of very short sparks are given off, of a length equal to the thickness of the layer of clothing between the roller and the skin. These short sparks produce a very strong sensory effect, and the roller electrode must therefore be used only with very rapid movements, otherwise the sensation becomes unbearable. It is a most valuable instrument in certain conditions and its effects are highly stimulating.

98. **Distinction of poles.**—To test the polarity of the machine. Take the earthed point electrode in the hand and present it to a knob of the machine in action. Gradually bringing it nearer and nearer, as it approaches the positive knob a star of light will appear on the point even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost into contact with the knob, then small sparks pass. If approached to the negative

pole in the same way the discharge takes the form of a visible brush or spark when the point is still at a distance of two or three inches from the knob. It is easy to recognise these differences in the discharge to the point, and from them to know which pole is positive and which the negative.

99. **Operative procedures.**—The patient is to be seated on a stool or chair on the insulated platform, and the brass plate connected with the machine by a wire or chain or brass crook. On the brass plate is placed a thick bundle of newspapers (of about the size of the "Illustrated London News") and on that the patient rests his feet. The machine is then set in action and its polarity tested. Then bring the positive or the negative pole into contact with the conductor to the platform and take the other one to the earth connection (fig. 58). The patient is then charged positively or negatively as the case may be. The presence of nails in the seat of the stool is undesirable.

100. **Simple charging or electrification.**—As soon as the patient becomes charged he feels certain sensations. The hair begins to move, and on the scalp and face and to a less degree on other parts he feels as if lightly touched by gossamer or cobwebs. If any piece of furniture or other object or person be near he may feel a breeze blowing towards him from it. If the platform is too near the machine this breeze will be particularly felt from the direction of the grounded pole of the machine. The platform therefore should be two feet or more away from the side of the machine and from any furniture or the walls of the room, and the friends of the patient must be warned not to touch or hand anything to the patient, otherwise a spark will pass between them and both will receive a shock.

Simple charging (positive or negative) may be continued for fifteen minutes or longer. Its effects are agreeable and tonic. It is the mildest form of statical treatment and is usually given not alone, but combined with the breeze to the head or spine or both, it is also a necessary part of all statical treatment administered to a patient on the insulated platform. Usually the patient is charged positively because that is the natural condition of charge of a patient in the open air or on a mountain side. It has been said that the negative charge produces feelings of prostration while the positive produces invigoration. This is probably incorrect at least it is not supported by everyday experience, though the idea serves to decide that when simple charging is desired the positive charge shall be preferred.

101. **Charge and discharge.**—In addition to the continuous electrification described in the last paragraph, there is a method of alternately charging and discharging the patient which is described by Dr. Monell, and recommended by him as a more energetic tonic treatment than the simple charging. He has given it the name of "Potential Alternation," and it is performed as follows:—While the patient is being charged, the knob or ball electrode, grounded as usual, is brought near to the knob of the machine from which the patient is being charged. As it approaches, a sharp cracking spark passes and the patient is discharged, to be immediately charged again from the machine and again discharged in the same way as before. The chargings and dischargings follow each other with a rapidity which depends upon the activity of the machine and the width of the gap across which the spark must leap. The patient's hair can be seen to oscillate in

time with the sparks, especially if the head breeze electrode be in position during the application. This method has the disadvantage that the stream of sparks makes a distracting noise which some patients cannot endure. Other patients do not mind the noise so much and find the application not unpleasant.

102. **The breeze or brush discharge.**—If when the patient is charged on the platform, a grounded point electrode is presented to him he feels the sensation of a wind blowing towards him from the point; this is the electric breeze, or wind, or *souffle électrique.* It can be felt when the point is a yard away, but becomes much more strongly felt when the point is brought nearer, right up to the distance at which the discharge changes from the silent discharge to that of sparks. The safe distance varies according to the polarity of the patient. When he is positive the grounded point can be brought much closer without sparking than when he is negative. The breeze which is felt as a cool wind upon the bare skin acquires a pricking hot character when directed upon covered parts and the prickly sensation is greater when the patient is positively charged. Usually, therefore, the patient is charged positively, except when the mildest form of breeze is desired, as may be the case with timid or unaccustomed patients. The breeze produces a very grateful sensation when applied to the scalp, and to the nape of the neck, and it is usual to arrange a special electrode for this head breeze by means of a hinged arm supporting a wire tuft or tassel, or a crown shaped metallic arrangement. In figure 56 this is shown as a rod projecting out from one top corner of the case, it has an universal joint enabling it to be swung out or in and raised or lowered to bring it into place over the

patient's head as he sits upon the platform. The scalp can also be "breezed" by the point electrode held in the operator's hand.

The breeze is called the "negative breeze" when the patient is positive and *vice versâ*. The breeze can be varied in strength by varying the distance between the point and the patient's surface. When the strongest effects are desired, the point (single or multiple) is brought as close as is possible without sparking, the effect then is something like a douche of hot water, and may be so strong as to be unpleasant, especially if kept acting for long upon one spot. It is more easily borne if the electrode is kept moving over the surface. The effect of a strong negative breeze upon the spinal region and the back is very invigorating, and it leaves a warm glow or after effect. As the effect of clothing in modifying the sensations of the breeze discharge is so marked it is occasionally useful to vary the thickness of the clothing to suit the requirements of the case, and this can best be done by using a woollen shawl, which may be thrown over the patient at any part where the strongest stimulation is desired. All the fabrics used for clothing do not behave alike in modifying the sensations produced by the breeze, for occasionally the corsets (or the back of the waistcoat in the case of male patients) may prevent the breeze from penetrating satisfactorily. It is not often, however, that difficulties arise, and when they do it is generally possible to overcome them. Occasionally the metal parts of the stays, or buckles, or hair-pins, or fine gold chains worn round the neck, or a steel key chain in the side pocket will cause some pricking or discomfort at the wrong place, and must be attended to.

When the patient's skin and underclothing is very

moist from perspiration the effect of the breeze is greatly diminished, and occasionally in very close summer weather the roller must be brought into play instead.

The breeze may be modified and strengthened by interrupting the charge as it passes from the machine to the patient; this is easily done by moving the conductor of the machine a little distance from the knob which leads the current to the platform.

The effect of the breeze is to produce profound cutaneous sensory impressions which can be adjusted so as to be either soothing or highly stimulating. In many cases of neuralgic pain, including headache, the effect is quite magical, that is to say, the breeze skilfully directed upon the affected region for five or ten minutes will often remove the pain entirely. In addition to this local effect, which is often very valuable, there is a general invigorating effect from the breeze applied to the head, the nape, and the spine, for which patients are very grateful. The sensations may be compared to the effect of those douches used in hydropathic establishments, with the great advantage that they can be given to the patient without any removal of clothing.

103. **Treatment by sparks.**—For giving sparks the knob electrode is used and as the sensation of a spark is disagreeable they must be given in as skilful a way as possible to avoid all unnecessary discomfort to the patient. The important point is to give only one spark at a time and not a volley. To do this the knob, earthed as usual, is swept quickly in a curve past the place at which the spark is aimed so that it is away again and out of range before a second one can follow the first. With a little practice this becomes easy. The sparks may be repeated as often as it is judged to

be necessary. Long sparks must not be directed upon bony prominences nor upon any place where the bone is thinly covered with soft tissues, and great care must be taken to prevent any spark, accidental or other, to the testicles or to the female breast, or to the face. The length of the spark can be decreased by partially discharging the patient before giving the spark, and this is easily done by the operator placing his foot upon the edge of the platform, and so causing it to leak away part of its charge. Sparks from a knob are more severe than those from the point or roller; the sensation produced by a single well directed spark is just that of a blow, the sensation of a blow or shock depending mainly upon the sudden forcible muscular contraction caused by the spark. It is as well to give the patient notice just before each spark. With ladies the sparks must usually be weakened in the manner indicated.

104. **The roller: electric frictions.**—When the roller is rolled over a clothed surface showers of short stinging sparks pass off from it to the patient, and the thicker the layer of clothing under the roller the sharper are the sensations. Thus they can be made stronger by a woollen shawl thrown over the clothing, and milder by the removal of an outer garment. The sensation is severe and leaves a tingling glow behind it which persists for some time. To use the roller it is best first to discharge the patient by means of the foot on the platform, and then quickly to put the roller in place, withdrawing the foot and sweeping the electrode over the surface immediately. All should be done in a few seconds, or the patient may protest. As in the case of long sparks, patients like to receive notice of the roller if it is to be applied to any part of the back where they cannot see it coming.

105. **The Leyden jar.**—This apparatus (see § 20) was discovered in 1749. Owing to the arrangement of its coatings it has a large capacity, and in its discharge there is a larger "current" than in the spark from the prime conductor of a machine as ordinarily constructed.

This makes itself felt as a more severe shock, when the discharge takes place through any portion of the body. The Leyden jar is therefore used when it is desired that the patient shall receive a painful shock.

In former days the comparative feebleness of the machines in use made it necessary at times to use Leyden jars to secure the strong effects which can now be produced more agreeably by the ordinary spark discharge from a knob electrode. They were used by first charging them from a machine and then bringing them to the patient and discharging them through him by means of conductors. They were also used in connection with an apparatus known as Lane's discharger, with ordinary cords and electrodes, like those described in the last chapter, and in a book on "Electricity and Medical Electricity" written by Adams in 1791, the frontispiece illustrates a physician of the period electrifying the muscles of a child's forearm in this manner.

This mode of treatment, however, seems to have been completely forgotten, for it is not mentioned in later writings so far as I am aware. In recent years an analogous method of using Leyden jars has been devised and brought to perfection by Dr. W. J. Morton of New York, and, as worked out by him, it has now become a very useful part of a statical outfit and has met with universal acceptation.

106. **Dr. Morton's method.**—In the illustration of the Wimshurst machine (fig. 55), two Leyden jars are

shown with their inner coatings connected to the prime conductors, one to each; the outer coatings are also connected by a wire, which can be removed at will. When the outer coatings are disconnected, or the jars are removed entirely, the machine in action produces a stream of thin purplish sparks, and if the finger be placed between the discharging electrodes, the sensations, though unpleasant, are of the nature of a slight pricking rather than of a shock. If the jars are now connected to their respective electrodes, and their outer coatings are joined by the wire, the sparks between the electrodes alter their character, becoming less numerous, much brighter, much longer and much more noisy. They also produce severe shocks if the fingers are placed in their path. As the distance between the knobs of the discharging electrodes is increased the sparks become louder, more vivid and less frequent, until the air gap is too great for the discharge to cross. The Leyden jars are fitted to the machines to make their discharges more powerful. If the wire joining the outer coatings of the jars be interrupted by a short air gap, sparks will leap across it simultaneously with those passing between the electrodes.

Many machines are fitted with a pair of binding screws in the circuit joining the outer coatings of the Leyden jars. This makes it easy to connect or disconnect this part of the circuit. When a wire is used to bridge over the interval between the binding screws the outer coatings are connected, when it is removed they are disconnected. Dr. Morton of New York has advocated the use of this portion of the circuit between the outer coatings for purposes of treatment. With a pair of ordinary conducting cords and electrodes (fig. 62) attached to the binding screws mentioned

above, Leyden jar shocks can be administered to a patient, and their severity can be controlled by adjusting the distance between the discharging knobs of the prime conductors. When the machine is in action a shock is felt by the patient every time a spark passes between the discharging knobs. Dr. Morton has given this method the name of treatment by "static induction," and the utility of the method is undoubted for purposes of treatment. Further, Dr. Morton has claimed that

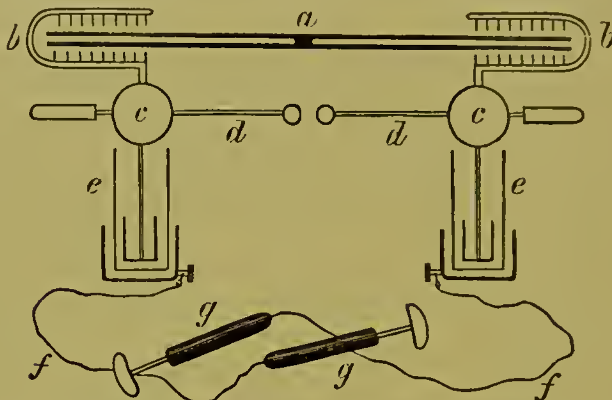


FIG. 62.—Plan of Dr. Morton's method. *a*. Plate of machine. *b*. Collecting combs. *c*. Prime conductors, with discharging rods, *d*. *e*. Leyden jar. *g*. Wires and electrodes attached to their outer coatings.

by the use of very small Leyden jars and with the discharging knobs very close together, the shocks become almost painless, while still setting up vigorous contractions in the muscles, and may then be made extremely useful for purposes of testing. It is doubtful, however, whether this method is less painful than the discharge of a well designed induction coil.

It is of the utmost importance to adjust the sparking distance between the discharging electrodes on the machine before com-

mencing the treatment; from an eighth to a quarter of an inch is generally sufficient; indeed, with quarter inch sparks, the treatment is severe; but the severity of the shock depends also upon the size of the jars, and is more severe with large jars.

Modern statical machines for medical treatment are now generally fitted with pairs of Leyden jars of several sizes for Morton's method, and have a simple switch arrangement for connecting or disconnecting the jars as required. The rate at which the shocks follow each other is determined by the speed of the machine. The effect produced is comparable to that of a slowly acting induction coil, and moistened electrodes applied to the bare skin are to be used.

By a further application of a helix of wire between the outer coatings effects like those of the Tesla coil can be obtained, see below, § 110.

107. **General effects of statical treatment.**—We may distinguish two sets of effects produced by statical applications; the one a general one, the other local. The former, though vague in description, is yet of quite definite nature and can perhaps best be called a general stimulating or "invigorating" tonic effect. The patient becomes more bright and alert, feels more lively and generally is improved in health if ailing or fatigued. For example, a medical man, who came to see my machine in order to be instructed in its use, was charged on the insulating platform and received an application of the negative breeze to the head and spine. After a few minutes he said that he had slept badly the night before and had been feeling very uncomfortable and tired but that the application had completely removed his discomfort. Statements of that kind from patients are not at all unusual. In morbid conditions of debility from various causes this effect of

the static machine can be of considerable permanent value.

108. **Clinical experiences.**—Dr. Imbert de la Touche has obtained results which tend to support the view that the electrostatic charge modifies the metabolic processes in some way. He has reported cases of obesity cured by this method, and speaks with confidence of its great value in "obesity of nervous origin," particularly when anæmia, headaches, and insomnia co-exist.

Dr. Dignat examined the pulse-tension in eleven patients and found that out of sixty-two observations the tension was raised in thirty-six, remained unaffected in twenty-four, and was lowered in two.

Dr. Vigouroux has expressed the opinion that the treatment by electrostatic charge acts chiefly upon the function of nutrition and upon the nervous system. Sleeplessness and languor disappear soon after the commencement of the treatment, the appetite too becomes increased; as for the urine, the urea augments and the uric acid diminishes, and the flatulent dyspepsia, so common in neurasthenics, is rapidly ameliorated.

Statical applications undoubtedly act upon the function of menstruation. With patients receiving a course of treatment for conditions quite unconnected with the generative functions it is common to remark some effect upon the menstrual periods. Professor Doumer* of Lille has published his notes on 400 women treated by static electricity. In 342 the uterine functions were quite normal; in the rest, 58 in number, there was some complaint of menstrual trouble, mainly of the nature of dysmenorrhœa. Among these patients there was a hastening of the commencement of the period in

* *Archives d'électricité médicale*, 1897, p. 96.

68 per cent., and an increase of the flow in 77 per cent. Among the 400 cases there were 178 who had some pains or discomfort about the date of the commencement of their periods, and 73 per cent. of these, 130 persons, were relieved of these symptoms, while the remainder were not. Menstrual irregularity was present in 51 cases and quickly disappeared in 31. These results followed for the most part upon simple electrostatic charging but the breeze or the roller applied to the lumbar region produced a more prompt result.

Truchot* has reported the results of some experiments upon himself, in which he was charged once or twice daily for a week. Each charging period was of fifteen minutes duration, but it is not specified whether the charging was positive or negative. The points attended to were the pulse-rate, the temperature, and the urine; the force of the grasp was also determined by means of a dynamometer. These points were observed for the week preceding the commencement of the electrifications, and for the week which followed.

The pulse was increased in frequency after each charging, being raised from 65 to 80, but apart from this immediate effect there was also a gradual rise in the average daily rate so that after the fifth or sixth charging the pulse remained at 80 for the whole day, and only began to return to its normal frequency two days after the chargings had been discontinued, finally reaching its normal rate of 65 per minute at the end of a week. The temperature also showed a gradual rise, being 97·9 at the beginning of the treatment, and 99·3 at the end of the week, returning slowly to its former level during the next few days.

* *Archives d'électricité médicale*, Feb., 1894.

The strength of grasp was augmented by each charging, rising from 42 to 44 kilogrammes after the first time; from 41 to 43 after the fourth, and from 40 to 42 after the sixth, but, as these figures show, there was a progressive decrease in the muscular power during the week of treatment, and the decrease was gradually recovered from during the following week, when charging had been discontinued.

The analyses of the urine, though a little difficult to interpret, show at first an increased proportion of urea to total nitrogen, followed by an increase in the total nitrogen with a fall of urea, which Truchot interpreted by supposing that at first metabolism was increased and internal oxidation was improved, but that afterwards there was increased tissue waste with less perfect oxidation; here again the effects of the treatment were perceptible for several days after its discontinuance. His general condition showed increased appetite for the first day or two followed by a diminution; sleep became disturbed, and a feeling of languor and feverishness developed itself. Thinking that perhaps the season of the year (July and August), and the fatigue of the summer session might have contributed to his weariness, the experiments were repeated between Oct. 15th and Nov. 15th after the repose of the long vacation. The results, however, were precisely the same, the temperature rose from 98·6° to 99° after four sittings. The pulse rose from 64 to 79, the feelings of fatigue returned.

The body weight does not seem to have been taken, and no light is thrown upon the question of the difference between the effects of positive and negative poles.

Of more importance than the experiments last noted are the numerous clinical results which are observed in the treatment of various forms of general or of nervous

debility. Dr. Monell reports strongly on its value in cases of neurasthenia in its various forms, and in the treatment of insomnia and mental fatigue; and he quotes from several recent writers on the subject of the treatment of certain forms of insanity and morbid mental states in which favourable results have followed statical applications, particularly in melancholia. In the nervous disturbances about the time of the menopause I have seen very decided benefit from simple static charging with the use of the negative breeze.

109. **Local applications.**—In the second class of *local* effects, the action depends very greatly upon the peculiar stimulation of the sensory nerves of the skin which can be produced by local applications with the point or roller electrode.

These sensory impressions can be made to vary from a cool and gentle breeze effect to an intensely pungent pricking, and much of the success of static applications depends upon the adjustment of the degree of cutaneous stimulation to the nature of the individual case. It is in this wide range of the sensory stimulation and in its peculiar qualities that much of the value of the machine for the relief of painful states lies.

The effect of breeze discharges upon painful affections of cutaneous nerves, as, for example, in headache, in neuralgia, or in neuritis with pain, is very striking. One may often see patients move so as to bring the tender area more directly into the line of the discharge, as though to obtain the fullest effect, and often they may be heard to utter expressions indicative of the immediate relief they are deriving from the application. With the negative point (the patient charged positively) there is not much risk of unintentional sparks, for sparking does not occur except with the point at very

close quarters. When for any special reason the patient is negatively charged, and the point therefore is positive, sparks may occur even across a distance of four inches or more, and must be guarded against.

The most intense cutaneous stimulation is that produced by the roller electrode ; and the severity of the application demands that it shall be used only for brief periods of a few seconds at a time. Regard must also be had to the thickness of the layer of clothing over which the roller is moved, as the sparks will be longer and stronger with a thicker layer. In approaching the roller to the patient a quick movement is necessary, to reduce the number of the stray sparks which pass as soon as the roller comes within striking distance. They can also be diminished by partially discharging the the patient by placing one foot on the platform until the roller has come into contact with the patient.

The action of the breeze upon the skin itself is shown by its effects in certain skin diseases. It has been frequently noticed by others and it has also come under my own observation that patients receiving applications of the breeze to the scalp find that the hair ceases to fall out. In pruritus, which is so intractable to many forms of treatment, the breeze has a markedly beneficial effect. In psoriasis, eczema, and varicose ulcers of the leg the same is true.

The local action of a strong breeze upon the skin through woollen clothing remaining plainly visible for some hours afterwards in a persistent reddening or in the form of urticaria-like elevations.

In addition to effects produced by means of cutaneous sensory stimulation, we have the shock or commotion of the contractile tissues which is produced by the application of a spark from the knob. This shock relieves

many deep seated pains of a myalgic nature, and often relieves them instantaneously. Probably it acts, in part at least, by a sort of forcible wrenching of muscle fibres. Often it is useful to request a patient with a pain in a muscle to assume an attitude which provokes the pain or increases it, and then to apply the spark or sparks to the painful part. In lumbago, deltoid rheumatism and other so-called rheumatic muscular pains, the treatment by sparks relieves promply.

110. **High frequencies and high potentials.**—The introduction of alternating currents for commercial purposes, and the ease with which high potentials can be obtained through their use by the aid of transformers makes it possible to subject the body to alternating high potentials and to examine the physiological effects produced. With the electrostatic machine the process of insulation and charging raises the patient's body to a high potential, positive or negative, according to choice, and the potential is maintained during the action of the machine. By attaching an insulated patient to one pole of a high pressure transformer a charge which is alternately positive and negative can be applied to him. The experiment is not to be undertaken without the most careful insulation. If the patient should by any accident become connected to earth during the charging, as might happen in various ways, as for example, by being touched by a bystander, his body would become the channel for a current to earth which might easily attain a dangerous magnitude; and as a matter of fact many persons have been killed by coming into contact with a high potential conductor when they were not properly insulated from earth. It has been already explained why there is no danger of accident with the electrostatic machine (§ 90) and it is

quite possible to arrange matters with the transformer so as to get rid of all serious risk by the use of adequate resistances, or of transformers of very high self-induction and small output. No experiments, however, have yet been made in this direction; and the effects of a high potential charge alternating at the rates usual in commercial currents, ranging between 50 and 120 complete periods a second have yet to be studied.

High frequency experiments.—When a charged conductor discharges itself, it happens under certain conditions of the discharging circuit that the discharge is an oscillatory one, that is to say the direction of the discharge current is alternating. These oscillations quickly die away, but while present they may have a periodicity of millions per second.

Of late years Elihu Thomson, Nikola Tesla and D'Arsonval have developed the study of these "high frequency" phenomena, and have obtained some remarkable results. The apparatus required is comparatively simple; the principle is to charge Leyden jars whose outer coatings are connected by a helix of wire, as in figure 63. The inner coatings of the jars terminate in knobs whose distance apart can be adjusted to suit the sparking distance of the charging electromotive force. The jars can be charged from a Wimshurst machine, or from an induction coil of large size, or, through a high potential transformer, frcm the alternate current supply mains. The output is greatest in the latter case and least in the first method.

The jars when charged to a certain potential discharge across the air gap, and oscillations are set up in the helix connecting the outer coatings, and the helix becomes the seat of electro-magnetic induction effects, comparable to those of the primary circuit of an induc-

tion coil, so that wires leading from the two ends of the helix yield a current, as do the wires of the primary current of a coil. In fact the apparatus is a modified induction coil, the current being supplied from the jars instead of from a galvanic cell, while the spark gap takes the place of the contact breaker, and the suddenness of the discharge by causing very rapid changes in

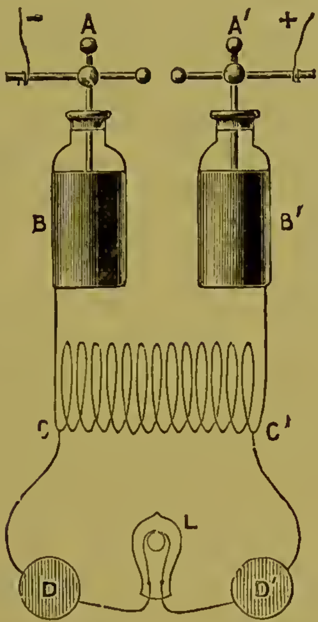


FIG. 63.—Arrangement of apparatus for high frequency experiments.

the magnetic field of the helix, sets up very powerful induction effects, both in the helix itself (self-induction), and round it, a secondary coil wound over the helix giving very conspicuous effects. D, D′, in the figure, represent two persons holding between them an incandescent lamp L, and having their other hands connected to the terminal points of the helix, under these

conditions the current through the lamp traverses the arms and trunk of the two experimenters and the lamp glows brightly, though they feel no shock.

If the helix be placed in a vessel of oil, and a secondary coil be wound on a wide glass tube placed over the primary to prevent sparks from passing between primary and secondary, the arrangement is that of a Tesla coil. A stream of crackling sparks several inches long will pass between the terminals of the secondary coil, but when the body is placed in the circuit little or no shock is felt, but only a warm glow and a partial anæsthesia of the region in contact with the electrodes.

This experiment and others of a similar nature have given rise to a belief that with high frequencies of alternation there is no danger even if large currents are passed through the body.

That the current through the lamp must have been two ampères, as estimated by D'Arsonval, is almost incredible, for a current of that magnitude from any ordinary source of electrical currents, whether direct or alternating, would destroy life, and produce serious burns of the tissues at the points of contact.

One suggested explanation of the incandescence of the lamp filament is that at very high frequencies the resistance of the filament is enormously increased, and a much smaller current at a proportionately higher voltage will make it glow. Another explanation given is that the rushes of current are very large while they last, but have so brief a duration that the total current passing in a given time is comparatively small; this, however, does not explain the difficulty of the absence of shock. Others, again, incline to the belief that the energy dissipated at the lamp filament is not so much an electrical current as a molecular disturbance, or

"bombardment," and that the actual current may be remarkably small. This is supported by the incandescence of a lamp when fixed to one electrode only of a high frequency coil, here the true current must be quite small and yet the lamp glows.

Although it is a fact that with a high frequency apparatus no shock is felt when the hands are in good contact with the electrodes, yet if there be an air gap in the discharging circuit the shocks at once become severe, and the wider the gap the more severe are the shocks. This observation is not alluded to in the published accounts of D'Arsonval's experiments. Dr. Hedley has further shown that if the electrodes in contact with the skin are progressively diminished in area a point is reached with small sized electrodes, when a distinct sensation becomes perceived, and he has very rightly argued that if the rapidity of alternation be the only factor which makes the current imperceptible, it should be as little felt with electrodes of small surface as with those of large surface.

The progressive increase of sensory effect as the area of contact is diminished, suggests that the concentration or density of the current is an important factor, and this again makes it probable that the total actual current flowing must be one of very small magnitude.

These paradoxical effects have given rise to much discussion, but further investigation is necessary before the real explanation of them can be arrived at.

Accounts of D'Arsonval's investigations, with illustrations of the arrangements of his apparatus will be found in the French Electro-therapeutic Journals for 1893 and 1894, and in the *Electrical Review*, March 23rd, 1894.

The practical applications of high frequency dis-

charges to therapeutics have been mainly developed in France. The current led off from the primary helix

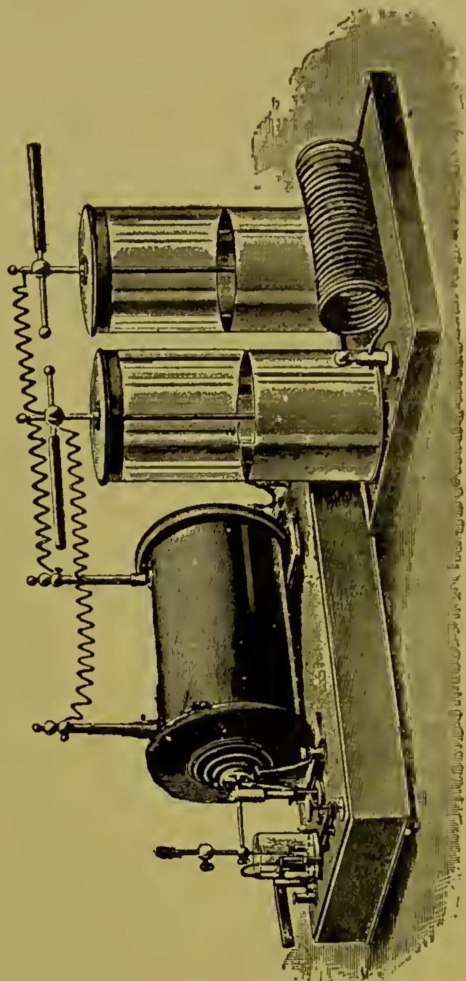


Fig. 64.—D'Arsonval's high frequency apparatus, showing Leyden jars with outer coatings joined by a helix and inner coatings fed by an induction coil.

joining the outer coatings of the jars (fig. 64) is more often used than the current of a secondary helix or

Tesla coil. The patient may be attached to one terminal of the helix while the other is joined to a plate or sheet of metal brought near but not attached to the patient. In this way the metal plate and the body of the patient form an arrangement like the two coats of a condenser, which is alternately charged and discharged as the potential at the ends of the helix rises and falls. The apparatus is arranged in the form of a couch; the patient lies upon insulating cushions which separate him from the metal sheet which is fixed beneath. It is called the "condenser couch" or "*lit condensateur*."

Or the helix itself is made large enough to enclose the patient as in a cage. It may be arranged vertically with the patient standing within it, or horizontally, the patient lying down. In neither case is there any contact between cage and patient, but the currents in the cage or helix induce currents in the patient within; this is called treatment by "auto conduction." Thirdly the patient may be put in direct circuit with the ends of the helix by ordinary wire connections, wetted pads, or arrangements of arm-bath or foot-bath (see Chap. X.). These methods, devised by D'Arsonval, will be found fully described and illustrated in the *Annales d'Electrobiologie* for January, 1898, in an important paper by Professor D'Arsonval himself, and in the same number will be found a paper by Oudin on the applications of these high frequency currents to diseases of the skin and mucous membranes, which gives further details as to operative procedure.

The field of treatment in which high frequency currents are especially indicated is that of diseases due to nutritional failure (*valentissement de nutrition*) such as gout, rheumatism, diabetes, obesity, debility.

The physiological effects upon which their application is based are the very marked increase of metabolic activity which has been observed in experiments with these currents upon men and animals, thus d'Arsonval reports the output of CO_2 in the case of a human being as being raised from 17 litres to 37 litres per hour. Associated with this there was a considerable increase in the production of heat, namely from 79 calories to 127 calories per hour, the body temperature remaining steady at a normal point. The amount of urea secreted is also raised.

The method is essentially a method of general electrification and the results it gives are somewhat similar to those obtained with the static machine as already described or with the electric bath, which will be described later. Each of these methods has its special advocates but the selection of one or other for use will depend a good deal upon the resources of the individual medical man. Thus one will have special conveniences for an electric bath, another will find a static machine more suitable and so on : good work can be done by all the modes of general electrification, and the high frequency methods of D'Arsonval have not as yet been shown to possess any conspicuous advantages over the others, as far as general electrification is concerned, though they may have certain special advantages for local applications, as in skin diseases. In Chapter IX. the subject of general electrification is considered at some length.

CHAPTER VII.

PHYSIOLOGY.

The resistance of the body. Diffusion of current in the body. The action of electrical currents on living tissues. The motor nerves and muscles. Unstriped muscle. Sensory nerves. Refreshing action. Trophic effects. Electrical osmosis. Lethal effects. Magnetism.

111. **The resistance of the body.**—The body is a conductor exactly in the same way as saline solutions or moist sponges are conductors, that is to say, it is an electrolyte, and the tissues between the electrodes during the passage of a current are in exactly the condition of the liquids in an electrolytic cell, consequently the passage of the current causes the accumulation at the positive electrode of acids, chiefly hydrochloric, from the abundance of sodium chloride in the juices of the body, and of bases, chiefly soda from the same reason, at the negative electrode. The region between the poles shows no evidences of either free acid or free alkali, and yet we feel sure that exchanges must be taking place all through the chains of molecules between anode and kathode. Moreover, it is not reasonable to assume that the changes only occur in the fluids of the intercellular spaces, for they must also go on in the whole of the cell substance which is traversed by the current.

Dr. Stone,* in a careful study of the resistance of the human body, arrived at the figure of one thousand

* Lumleian Lectures, 1886.

ohms as the average resistance from foot to hand, and from foot to foot, when the contacts were made through large vessels of salt water into which the extremities were plunged. In this way he thought he had succeeded in eliminating the resistance of the skin, and considered that the figures obtained indicated the resistance of the deeper tissues only.

Professor G. Weiss* measuring the resistances from hand to hand with contacts made through bowls of salt water, found the average resistance in sixteen men to be a little over thirteen hundred ohms, and in seven women fifteen hundred ohms; the reason why the latter showed a higher figure is not very clear, particularly as the skin of women is generally believed to be more thin and delicate than that of men. It may have been due to the smaller immersed area in the case of the women, or perhaps to a lesser number of sweat glands and hair follicles; the difference, however, is not great, and would probably be less apparent if a larger number of cases had been measured.

In some measurements made in the *post-mortem* room at St. Bartholomew's Hospital, the resistance of the tissues, not including the skin, was found to range between two hundred and four hundred ohms, with average sized medical electrodes for the contacts.

Different observers have given the most widely divergent figures for the body resistance, the range being from one thousand to two hundred thousand ohms, according to the nature of the contacts used in the experiments. The human epidermis, when dry, offers a very high resistance indeed, especially if it be at all thick and horny like that of the palms of the hands and the soles of the feet. When moistened and permeated

* *Arch. d'électricité médicale*, 1893.

with water or salt solution, its resistance becomes much less; the internal tissues of the body have a comparatively low resistance, and the only value of most of the experimental determinations of resistance is that they show how enormously the resistance of the skin may vary. The resistance offered by any patient depends upon the following points:—*First*, the state of the skin, whether thick or thin, dry or moist, cold or warm. *Second*, the area of the electrodes and the efficiency with which they are brought into contact with the surface of the body. *Third*, the electromotive force of the battery used in the test; and *fourth*, the duration of the test. With low electromotive forces, one volt for instance, the resistance is much greater than with higher voltages, and polarisation becoming set up at the surface of the electrodes tends to make the apparent resistance even greater than it really is. With higher voltages the passage of the current produces at first an increased vascularity of the skin under the electrodes with diminution of the resistance, and if the current be continued, so as to cause the skin to be gradually destroyed, the resistance is further diminished.

During the progress of treatment the number of cells in circuit must be reduced gradually to compensate for the fall in resistance, if this is not done there is a risk lest the current should rise to too high a figure, and injury may result to the patient from want of attention. Burns of the skin are sometimes produced in this way.

The resistance of a patient is almost entirely a resistance at the contact of the electrodes with the skin, it can be varied in many ways, and it does vary from day to day in the same patient. As for the resistance of the tissues beneath the skin, it is a matter of a few hundred ohms. Careful measurements of the resistance

of patients, and statements as to the degree of resistance in different morbid states cannot therefore be of much value or importance.

When the electrodes are applied to mucous surfaces, or are in the form of needles thrust through the skin, the resistances are much lower. With needles of both poles inserted into a nævus, the resistance may be as low as a hundred ohms, and it is said that with needles in an aneurysmal sac readings as low as ten ohms have been recorded.

The medical practitioner is concerned with the resistance of the body mainly as it affects the question of treatment, and the number of cells required to drive the proper current through the patient. Under conditions of medical practice, and using moistened electrodes, the resistance of the body, when the skin is well wetted with warm water, is about two or three thousand ohms, that is to say an electromotive force of twelve volts (eight Leclanché cells) will pass a current of four to six milliampères. If one electrode is placed on the palm of the hands the resistance will be at least double. Difficulties in testing muscle sometimes occur from not remembering this point, for an electromotive force with which contractions are easily set up in the muscles of the forearm and of the back of the hand, may produce no effect at all when the testing electrode is transferred to the palm. A glance at the galvanometer will, however, show the reason why, by indicating a smaller current and a greatly increased resistance.

An excessive resistance is sometimes offered by the dry skin (and accumulated epidermal cells) of patients who have been long confined in bed, especially when there has been little or no perspiration for some time, and this occasionally presents a considerable obstacle

to the electrical examination of the muscles of such patients, and unless care is taken it is apt to mislead.

During the treatment of a patient the resistance of his body may be calculated by Ohm's law from the galvanometer reading, and the electromotive force of the cells, if that be known. For example, with twelve Leclanché cells in good order the electromotive force will be eighteen volts, and if the current through the patient be four milliampères the resistance may be taken as follows:—$R = \frac{E}{C}$, $E = 18$ volts, $C = \cdot 004$ ampère, therefore $R = \frac{18}{\cdot 004}$ or 4500 ohms. In this way an estimate quite close enough for most cases can readily be formed. When exact measurements are required a Wheatstone's bridge arrangement, with a battery current and a galvanometer, or with an alternating current and a telephone (Kohlrausch's method), must be employed (see references given in § 32, or Kempe's *Handbook of Electrical Testing*). The latter method has been preferred, because it eliminates the difficulty of polarisation, but this has probably been over estimated, and the telephone method introduces other difficulties of its own. Professor Weiss' paper* indicates a method of overcoming the difficulties of polarisation, when the battery and galvanometer method is used.

112. **Diffusion of current in the body.**—The density of the current (§ 34) and the diffusion of the current as it passes through the tissues from one electrode to the other, have an important influence upon the results produced. It has already been stated that in large and heterogeneous conductors, like the human body, the current spreads out in sheets as it

* *Loc. cit.*

passes from anode to kathode. Dr. De Watteville has very clearly illustrated this as follows:—He says: "The reader may picture to himself the electrical density at any point of a circuit of variable diameter by representing the strength of a given current flowing through it by a certain number of lines. These lines expand in the wider portions of the circuit owing to the diffusion, and become crowded together in the narrower parts. A crowd issuing through a narrower door, and through gradually expanding passages, and finally reaching the street, like electricity flowing through a circuit of variable diameter, is said to be densest at the narrow exit, and it thins out, and has a lower density as it reaches the wider outlets."

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing direct lines from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

Fig. 65 shows the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between the electrodes, for some of the lines which indicate its direction, actually commence their course by curving downwards through the tissues below the electrode.

It follows that parts of the body which are outside

the direct line of the electrodes may be influenced by the current passing between the electrodes, and it will be seen from the chapters on treatment that this may sometimes be advantageous, and sometimes the reverse.

It also follows that the size of the electrodes is of importance in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quantity of current is flowing, will

FIG. 65.—Lines of current diffusion round an electrode.

be greater than when large electrodes are used; this point has been already alluded to in § 79, and will be again referred to later.

113. **The sensation of shock.**—The effect of electric currents upon the nervous system seems to depend partly upon the magnitude of the current, and partly upon the rate of change in this magnitude. It is possible to tolerate the gradual introduction or the steady passage of twenty or thirty milliampères through

the body if the contacts with the skin at the electrodes are large and good, but the sensation of shock is severe, if currents of five milliampères are rapidly set up in the body; and when the current is broken rapidly its sudden cessation also produces a far greater impression than that felt while it is running steadily. This shock at the break or opening of the circuit is difficult of explanation, and nothing comparable to it is observed with inanimate electrical circuits or apparatus, for it is not of the nature of an induction effect; the explanation which is offered in physiological textbooks, namely, that a sudden fall of potential is an effective stimulus to a nerve fibre is no explanation at all.

The important part played by the rate of change of current in producing physiological effects is clearly shown by what has just been said of the current slowly or suddenly made and broken through a circuit which includes the body; the part played by the quantity of current passing is seen by a comparison of the effects of a spark drawn from the prime conductor of an electrical machine with that from a Leyden jar discharge. A spark a quarter of an inch long taken from the former produces only a slight impression, but a spark of the same length from the jar gives a violent shock. The difference between the two is largely a difference in quantity of current passing. In both cases the electromotive force is very high, and the total quantity is small; but, in the case of the Leyden jar, there is, for the extremely brief instant of the discharge, a fairly large current, because of its capacity as a condenser.

114. **Electrical phenomena of nerve and muscle.**—Nerve acts as a conductor, whether it be alive or dead, but there is a peculiarity in its conductivity

which is unlike that of saline solution, viz., its resistance in any direction does not depend solely upon its sectional area as would be the case in homogeneous conductors, but it conducts more readily along the length of its fibres than across them, and the same peculiarity is also found in muscle and in wood.* Brenner has shown that in nerve the transverse resistance is as 5 : 1, and in muscle as of 9 : 1, as compared with their longitudinal resistances. It is probable that these differences in resistance simply signify that as conductors they are not homogeneous. Crushed nerve is also said to be a better conductor than fresh undamaged nerve.

Electrical currents in nerve and muscle.

a. Current of rest.—If the wires of a sensitive galvanometer be attached to two points in a removed portion of either nerve or muscle, the existence of a current will be made manifest by the deflection of the galvanometer needle, its direction being that which indicates a current passing through the wire from the central part of the piece of nerve to its extremities; this current is called the *current of rest.* It is more easily demonstrated in an excised and therefore damaged portion of nerve or muscle than in a part which is still lying uncut in the body; and indeed it is probable that this current of rest only exists in damaged tissue, and is not present in normal parts at all, but that it is set up by chemical changes resulting from the injury.

b. Current of action.—If while the galvanometer is attached to it, the nerve or muscle be stimulated in any way, whether by electrical, mechanical, chemical,

* This may well be compared with the phenomena of the conduction of heat in wood, which takes place at a different rate according to the direction of the grain of the wood.

thermal, or any other means, then the galvanometer needle will give evidence of the production of an electrical current by a momentary deflection in the opposite direction to that produced by the current of rest; this has been called the *negative variation* of the current, or the *current of action*. It is propagated in both directions from the point stimulated, and travels in nerve at the rate of 28 metres per second, and in muscle at three metres per second, that is to say, the disturbance of equilibrium producing the current moves at these speeds, which are very much slower than the rate at which an electrical current travels along a nerve, which is an entirely different thing. The impulse which passes along a nerve to cause muscular contractions or sensory impressions is not an electrical impulse, although there is an electrical change associated with it. If a nervous impulse were simply an electrical current it should be transmissible by an electrical conductor, as for instance a copper wire, but it is not so transmitted, neither will a piece of damaged nerve convey a nervous impulse, although it may readily convey an electrical current, moreover, the velocity of an electrical current in a conductor, such as a nerve trunk, is immensely more rapid than the velocity of a nervous impulse in a nerve trunk. Hitherto the current of action has not been made use of for diagnostic or therapeutic purposes.

115. **Electrotonus.**—During the passage of a constant current along a nerve certain alterations in the irritability of the nerve, and certain alterations in its conductivity are produced, this altered state is known under the name of *electrotonus*. Electrotonus then is the condition of a nerve during the passage through it of a constant current, but the effects in that part of the

nerve near the anode are not the same as those near the kathode, thus there is one altered state round the anode or *anelectrotonus* and another different altered state round the kathode or *kathelectrotonus*.

a. Anelectrotonus.—In the region of the anode the *irritability* of the nerve is diminished, the fall in irritability taking place at the moment when the circuit is closed, and remaining diminished till the circuit is again opened, when there is a return to the normal. Also the *conductivity* of the nerve for nervous impulses becomes diminished by the development round the anode of a resisting area through which nerve impulses pass only with difficulty.

b. Kathelectrotonus.—Round the kathode the closure of the circuit causes a *rise of irritability* which is maintained during the passage of the current, and returns to the normal level when the current has ceased to flow. The sudden rise of irritability at the kathode on closure is a stimulus to the nerve, and so also in a less degree is the rise from a diminished irritability to the normal at the anode on opening. The importance of electrotonus partly lies in the explanation which it affords us of the behaviour of muscle towards constant currents, at their make (closure) and break (opening). Electrotonus is also useful medically in giving us a clue to the treatment of disease, accordingly where it is wished to increase the irritability of a part the condition of kathelectrotonus should be set up by applications of the kathode, and conversely the application of the anode is to be preferred for inducing a state of diminished excitability, and so of relieving pain and spasm.

116. **Ascending and descending currents.**—When the electrodes are so placed that a line drawn from the positive to the negative poles runs in a direc-

tion from centre to periphery, the current may be spoken of as a "descending current," and conversely it may be called an "ascending current," when the anode is more remote and the kathode more central.

In the case of a nerve trunk which has been exposed and isolated, the conditions are different from those which exist in the case of a nerve which is being tested *in situ*, surrounded by other conducting tissues. In fig. 65 the lines of flow of current round an electrode are shown, and it is clear that they are not all parallel to one another, and that they traverse the nerve trunk in many different directions.

For this reason, it is now more usual to define an electrical application, not by speaking of the ascending or descending direction of the current, but by reference to the sign of the pole which is used as the active electrode, and inasmuch as the indifferent electrode is commonly applied to the trunk while the active electrode is applied to a limb, the current would usually be a descending current when the active electrode was negative, and ascending when the active electrode was positive.

The expressions "ascending" and "descending" current convey the idea that the direction of the flow in the interpolar region is of importance, while the phrases "the use of the negative pole," "the application of the anode," and so on, need not necessarily be taken to do more than signify the polarity of the electrode applied to the affected part.

Reference to fig. 65 not only shows that the lines of flow are in all directions, but that the current in traversing any particular point must leave it with a polarity opposite to that with which it enters it, for example, the nerve trunk represented in the figure as

traversed by the current is negative to the parts which lie nearer to the electrode, and is positive to those which are further away. All that can fairly be said of the region surrounding the positive electrode is that it is positive to areas which are more remote.

117. **Reactions of nerve and muscle.**—*a. Battery currents.*—The phenomena of the contraction of muscles when their motor nerves are stimulated by electrical currents are as follows:—If the indifferent electrode be placed upon any convenient part of the surface of the body, and the active electrode be then applied over a motor nerve, it will be found that with a current of one milliampère from a battery, muscular contractions begin to be produced as the circuit is closed, and with somewhat stronger currents contractions appear both at closure and at opening. With the active electrode negative the contraction at make or closure is easier to produce than when it is positive. The order in which they appear are:—

a.	Kathodal closing contraction		(KCC).
b.	Anodal ,,	,,	(ACC).
c.	Anodal opening contraction		(AOC).
d.	Kathodal ,,	,,	(KOC).

The symbols affixed are commonly used for convenience to designate the contractions, of these *b* and *c* require about twice, while *d* requires four times the current necessary to produce *a*.

The exact current needed to produce contractions varies with the excitability of the nerves, and with their position, a nerve which is superficially situated requires a smaller current than a deep seated one, because it receives a greater fraction of the current, as in the latter case the current is more diffused before it reaches the nerve, so that only a part of the current indicated

by the galvanometer is effective. For the same reason a patient with a thick layer of subcutaneous fat requires a larger current to affect his nerves than is the case with a lean person in whom the electrode can be brought into close proximity to the nerve to be tested. The electrode should be small in these experiments, as this allows us to concentrate the current more effectually upon the nerve. There is probably not very much difference in the irritability in different nerve trunks, but perhaps the facial nerve may be slightly more irritable than the others. At least the facial muscles can be thrown into contraction by smaller currents than those of the trunk and limbs, and when they are to be tested it is well to bear this in mind and so to save the patient some discomfort.

Dr. Verhoogen* gives the following figures for the contractions produced by stimulating the ulnar nerve at the back of the internal condyle of the humerus.

KCC	2 milliampères.	
ACC	3	,,
AOC	3·5	,,
KOC	15	,,

And these may be taken as representing very well the approximate magnitudes of current necessary to evoke the contractions of healthy muscles through their motor nerve trunks.

These figures are of value because they give the actual effects observed in a particular case, but they seem to be rather high, other observers have found one milliampère to be a sufficient magnitude of current for producing the minimal KCC contraction in superficially placed nerves.

It will be seen in the next chapter that it is con-

* *Revue internationale d'électrothérapie*, September, 1894.

venient to make use of certain nerve trunks which can easily be reached when the irritability of the motor nerves is to be tested. Those generally used for the purpose are the frontal branch of the facial nerve, the spinal accessory in the neck, the ulnar, and the peroneal; a standard size of electrode should also be used, and a disc three-quarters of an inch in diameter (about three square centimetres) is a suitable one.

In a normal muscle the effect of direct stimulation of its fibres is concealed by the effect produced upon it through its nerves, for the intramuscular branches of its nerve both receive the impression better, and transmit it to all parts of the muscle more rapidly than the muscle fibres could do it by themselves if no nerves were present. Still muscle *per se* is irritable and capable of responding to stimuli by a contraction; but for this it is necessary that the stimulus should have a certain minimum duration, rather longer than the minimum for a nerve trunk, accordingly it oftens happens that a muscle whose nerves have undergone injury may not respond to the rapid stimuli of induction currents, while they will still respond to the constant current slowly interrupted (see following chapter, "Reaction of Degeneration").

The contractions produced in muscle by the stimulus of the make and break of a constant current are momentary single contractions, and between the contraction at make and the contraction at break the muscle is quiescent and relaxed, although the current is traversing it. With strong currents of ten milliampères or more a condition of imperfect tetanus is produced, which has been named duration tetanus. Anodal duration tetanus, ADT, is less common than kathodal, KDT. The duration tetanus is not usually

seen in electrical testing, but in certain altered conditions it is more readily elicited than in health, and it will be considered in the next chapter.

If the makes and breaks of a battery current follow one another in rapid succession, the muscle passes into a state of tetanus or permanent contraction; provided the individual shocks succeed one another at the rate of twenty per second or upwards.

b. Induction coil currents.—As the discharge from an induction coil consists of a series of impulses or waves of current, unidirectional in the primary, § 72, but alternating in the secondary coil, and occurring about fifty times a second, it is reasonable to expect that their effect upon a motor nerve would be to throw the muscles into a tetanic contraction, and that is what is observed. If the apparatus be arranged to give single shocks, single contractions follow, exactly like those at the make and break of a battery current, in fact, each wave of current from a coil may be regarded as a make followed immediately by a break, the two contractions being fused by the comparative slowness of a muscular contraction, which occupies one-tenth of a second. The rise and fall of the wave with the coil are less sudden than the rise or fall when a battery current is made or broken. The opposite of this is frequently asserted, but it is not correct, for the current from a battery both rises to its full value and falls again instantaneously, while the rise and fall of a current from a coil is gradual, as shown by figs. 35 and 36, and may occupy a period of one-hundredth of a second. It has already been said that the effect upon the muscle is the same whether the stimulus be applied through the motor nerve trunk, or through the muscle itself. Under conditions of health, stimuli to the muscle are

really stimuli through the motor nerves of the muscle. In electrical testing it is usual to apply the electrodes to the muscles directly; the individual behaviour of the muscles is then more clearly seen than if they be thrown into contraction in groups through a common motor nerve trunk.

When an animal has been poisoned by curare, the nerves are paralysed, and stimuli applied to the muscle still produce contractions, though stimuli to the nerve trunks do not. Under these circumstances the muscle reacts both to induction coil currents and to battery currents, but the contraction produced by an electric shock is more sluggish than in a healthy muscle. It is not certain, however, that curare may not of itself alter the character of a muscular contraction, at least we are not justified in supposing that this drug permits of a complete distinction between the effect of electric shocks on nerve and on muscle. After section and degeneration of the nerve trunk the character of the muscle contraction becomes altered, as will be seen in the next chapter, but here too the alteration may be due to changes in the muscle as well as to the change in the nerve.

118. **Unstriped muscle.**—The effect of electrical stimulation upon unstriated muscle is not so sharply defined as with striped muscle. The general effect is that stimuli from either the continuous current, or the induction coil will set up a wave-like contraction, which is slow and sluggish, and tends to spread for a considerable distance from the point stimulated. The most effective method of setting up contractions in unstriped muscle appears to be by means of battery currents interrupted slowly. A long and careful account of the action of electricity upon unstriped muscle will be found

in Onimus and Le Gros,* based upon experiments on animals, but the conclusions arrived at are a little complicated and difficult to follow. They state that when peristalsis is present it may be arrested by an ascending, and quickened by a descending current; they also noticed that arrest of movement may occur in the region between the poles, together with contraction at the seat of the electrodes.

119. **Heart muscle.**—The habits of heart muscle are peculiar in their highly developed tendency to rhythmic contractions; electric stimulation tends to strengthen the action of heart muscle if it be timed to suit the natural rate of the rhythm; if the stimulation does not quite keep time with the heart beat it may effect a gradual change in its rate, until the heart may be brought to beat in time with the rate of the stimulation. If the stimulation be quite out of step with the rhythm of the heart it will tend to embarrass its action. A weak or moderate continuous current or a smooth unbroken succession of induction coil shocks may strengthen or accelerate the beat of the heart. Strong continuous currents destroy the rhythm of the heart, and cause it to stop in diastole, see below, § 126, and strong shocks from an induction coil do the same. The useful employment of electricity to strengthen a heart which has suddenly developed signs of failure is very difficult, and their is considerable risk of doing the patient more harm than good by injudicious electrification.

120. **Sensory nerves.**—Just as the electrical stimulation of motor nerves causes muscular contractions, so the stimulation of sensory nerves produces sensations. Accordingly, when an ordinary mixed nerve trunk is

* "Traité d'électricité médicale," Paris, 1888.

stimulated, its motor fibres set up contractions in the muscles supplied by it, and its sensory fibres convey to the brain of the patient experimented upon a peculiar sensation or *shock*, strong or weak, in proportion as the current is strong or weak. The peculiarity of the sensation also produces a mental effect, so that different patients appear to vary in their susceptibility to these sensations, thus it is said that if a current be transmitted from hand to hand through a line of people, some will say they felt the shock severely, and some only slightly.

a. The battery current.—In the case of the constant current, there is a sensation not only at closure and opening, but also during its steady passage, if the current be fairly strong, but not if it be weak.

The sensations are more perceptible at the kathode than at the anode, but a good deal depends upon the relative sizes of the electrodes; if one be much smaller than the other, then the greater density of current at the smaller one increases the cutaneous sensations there. If the electrodes be held still in one place, other sensations of a burning character soon become felt, and are accompanied by reddening, urticaria, or blistering of the surface, these changes and the burning pain are due to the formation of products of electrolysis. In the removal of hairs by electrolysis, the fine needle-like electrode introduced into the hair follicle feels much as though it were very hot. The nature of the surface of the electrode also modifies the sensation; and the current is less painful when the electrodes are firmly pressed upon the surface, because the contact is then better and the current is distributed over more points of entrance.

Bare metal electrodes applied to the skin produce

injury to its surface more quickly than do those covered with a layer of moistened wash-leather, or flannel, or the like, because in the former case the products of electrolysis are set free at the actual surface of the skin, while in the latter they are formed chiefly in the moist material which covers the electrode. With battery currents care must be taken to protect the skin from all accidental contacts with bare metal.

b. Induction coil currents.—A single discharge from an induction coil produces a sensation like that of a sudden make or break of a battery current, the severity of the shock depending upon the electromotive force and current in the circuit. An induction coil with its contact-breaker in action, produces a series of shocks in which the individual impulses may be perceived, unless they follow one another too rapidly.

At fifty interruptions per second the sensations begin to become fused, and at higher rates of vibration the sensation feels more smooth or continuous than before. With rapid vibration, one hundred per second and upwards, a benumbing effect becomes noticeable in the area of distribution of a cutaneous sensory nerve, if the electrode be applied to a point upon its trunk; this sensation of numbness being in addition to the effect felt in the place of contact of the electrode. With a small movement of the electrode away from the nerve trunk the numb feeling may disappear. The numbness is a true anæsthesia, both tactile sensations and the perception of painful impressions being very greatly blunted, and a glow accompanied by perspiration often succeeds, when the current is cut off.

When an electrode is moved over the surface of the skin systematically, the position of the cutaneous nerves can often be exactly localised by using a very small

electrode and a current which can just be felt, for whenever the electrode comes close over a sensory nerve trunk the sensation at once becomes quite strongly felt; from this it appears that a nerve trunk is more sensitive to the stimulation than the nerve endings are. In testing muscles it is of advantage to know the position of these "sensory points," in order to avoid them and save the patient from unnecessary pain. On the dorsum of the foot there are several, which are apt to become painfully stimulated when testing the electrical reactions of the interosseal muscles. A little exploration of one's own cutaneous surface affords the best way of learning the position of these superficial nerve trunks.

It is stated by Erb that the perception of the induction coil current is a function similar to the perception of painful sensations, rather than of tactile. This can be clearly seen in patients who have analgesia, without loss of tactile sensibility. This was very well illustrated in a case which recently came under my notice, the patient who could feel the touch of the electrode quite well, felt no shock at all even with very strong currents, and she was also unable to feel painful sensations when tested in other ways over the affected area.*

Perhaps the word "shock" should really be confined to those forms of electrical sensation in which there is muscular contraction, for the muscular sensation contributes largely to the peculiar feeling connoted by the word shock.

121. **Nerves of special sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations, thus stimulation of the olfactory

* For a minute analysis of all the phenomena of electrical sensibility see Bordier, "Sur la sensibilité électrique de la peau," Paris, 1896.

nerve produces a smell "like phosphorus," and stimulation of the optic nerve produces the impression of a flash of light. The optic nerve seems to be remarkably sensitive to small electrical currents, and the sensation of a flash of light is very easily produced by the small current obtained from a silver coin and piece of zinc put into the mouth, between the gums and cheek. When the metals are made to touch, the optical effect is distinct. Some observers have even thought that the colour of the flash seemed to depend upon the direction of the current, and that the kathodal closure gave a reddish colour and anodal closure a bluish one. These effects can be fully studied by a battery of four or five elements, with one pole at the nape of the neck and the other over the temple or eyelids. The accident which befell Duchenne, who applied a current of unknown strength to a patient's face, and apparently caused very serious damage to the sight of one of his patient's eyes, described at length in *Électrisation localisée*, 3rd edition, p. 15, may have been a retinal hæmorrhage due indirectly to the electrical application.

The auditory nerve.—This nerve also can be made to respond to galvanic stimulation. It is not so very easy in healthy individuals to produce the electrical reactions of the auditory nerve, for fairly strong currents are required, and some of the effects upon the eyes and brain make the experiment unpleasant; but the investigation is important, because of its bearing upon the treatment of *tinnitus aurium*, as the prognosis in any particular case turns largely upon the way in which the auditory nerve reacts. There is a close likeness between the formula of the auditory nerve and that of the other nerves. The kathodal closure produces a sensation of sound, which may continue during the passage of the current,

but the anodal closure does not; on the other hand the anodal opening produces a sound and kathodal opening does not. The formula then is:—

KC sound.
KD sound.
KO —
AC —
AD —
AO weak sound.

These auditory phenomena will be again referred to in a later chapter.

Galvanic stimulation of the nerves of taste is easily produced, and the simple experiment just mentioned for producing the optical sensation of a flash of light will at the same time produce a metallic taste, and by passing a current from one pole at the back of the neck to the other below the chin over the hyoid bone, the same metallic taste is produced.

122. **Other organs.**—Besides the physiological action of electricity upon muscle and nerve, it has an action on secreting glands, upon the circulation, and upon the brain. It is quite in accordance with what one would naturally expect that a current passing through a secreting gland or through its secretory nerves should cause increased secretion; and that a current passing through a viscus containing unstriped muscle should cause peristaltic contractions of that viscus, and there is no need for us to enter into detail at present by describing the particular behaviour of the uterus, of the bladder, or of the intestine, for these points will be better treated of later. (For vaso-motor effects see § 146).

In the case of the brain experimental physiologists have made much use of electrical stimuli in determining the situation of motor centres in the exposed cerebral

cortex. When a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, there is a disturbance of equilibrium, a feeling of giddiness, or an actual unsteadiness, with a tendency to fall towards the side of the anode, and sometimes there is conjugate deviation of the eyes to the side of the kathode, with a kind of oscillation or lateral nystagmus.

It has been supposed that the disturbance of equilibrium depends upon a state of kathelectrotonus of one hemisphere with anelectrotonus of the other; the former hemisphere being in a state of exalted excitability and the latter in a state of diminished excitability, their action is no longer balanced, and a sensation of giddiness is the result.

The brain is not easily influenced by induction coil currents applied to the outside of the skull, though responding readily when the electrodes are applied directly to its substance, but this is only because the currents of the required strength are so painful to the skin as to be badly borne. It is incorrect to suppose that the brain or the spinal cord are protected from electrical currents by their bony coverings.

123. **The "refreshing action" of the galvanic current.**—Dr. G. V. Poore* has reported some remarkable experiments upon what has been called by Heidenhain "the refreshing action" of the constant current; he investigated the fatigue of muscles produced when a weight is held out steadily at arm's length, and gives an instance of a patient who was able to hold out his arm horizontally with a weight of seventeen ounces in the palm for a period of four minutes,

* "Electricity in Medicine and Surgery," Dr. G. V. Poore, London, 1876.

and then complained of great pain in the muscles and fatigue, and declared his inability to go on but was relieved of his pain at once by the passage of a constant current in a descending direction along the arm. Another person was then experimented on in the same way; after holding out the weight at arm's length for seventy seconds, he felt pain and fatigue, but the application of the current at once removed both, and he continued to support the weight for five minutes and a quarter, and at the end of that time was willing to go on longer. Dr. Poore says: "similar experiments to these have been tried on several of the author's friends, and they all tend to show that the endurance of voluntary muscular action is enormously increased by the passage of a constant current, and the feeling of fatigue both during and after the prolonged effort is mitigated or entirely obviated."

Dr Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer, at intervals of ten seconds, gave an average of 48½ pounds for each squeeze, but eight more squeezes with the aid of the current gave an average of 59½ pounds, although they came ten minutes after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles. Capriati (*Arch. d'elect. médicale*) has recently confirmed and extended these observations.

124. **Trophic effects.**—Experiments were made by Dr. Beard* to determine the effect of general faradization upon the growth of some puppies, they were kept

* Beard and Rockwell, "Medical and Surgical Uses of Electricity."

under treatment for four weeks, being treated daily with an induction coil current; at the end of the time the two puppies which had been so treated had gained in weight faster and were perceptibly bigger than the two others, which had been kept untreated as control animals; however, other experiments gave conflicting results. It is reasonable to expect that the metabolism of the tissues should be increased by the vigorous stimulation, and that a young animal should increase in size in consequence, just in the same way as massage of the muscles increases their size and activity. In the treatment of children by electricity for paralysis, a great improvement in their general health has been often noticed by myself, and general electrification applied to children with rickets does them much good.

125. **Electric osmosis.**—The fact has been long known that a movement of electrolytic fluids comparable to osmosis takes place in the direction of flow of the current, namely, from the positive to the negative pole; and fluid can in this way be made to pass through membranes or porous diaphragms against the force of gravity; and it has been proposed to make use of this process for the introduction of drugs into the body through the skin. It is evident, however, that it is rather an elaborate method of administering a drug, and only in certain cases can it have any advantage over the methods of giving drugs by the mouth or hypodermically; besides, it would be difficult to know when the proper quantity had passed into the system. It was also hoped that in this way it would be possible to apply drugs locally, as for instance, iodide of potassium to a gumma, but this cannot be satisfactorily effected because the drug is carried off by the circulation quite as fast as it enters through the skin. Still,

there is one particular object which can be well and conveniently secured in this way, namely, the introduction of cocaine to produce local anæsthesia of a portion of the skin, this can be done very simply by covering the positive electrode with a layer of absorbent cotton well moistened with a ten per cent. solution of pure cocaine in guaiacol and holding it steadily to the part, with five milliampères of current the shin should become anæsthetic in about five minutes. The procedure is of value before small superficial operations, and in neuralgic affections. Either the pure alkaloid or its salts may be used as both are soluble in the guaiacol.

Many applications of electrical osmosis or cataphoresis, as it is also called, have been proposed; among them is one for the treatment of gouty deposits by salts of lithium. The affected part is immersed in a bath of warm solution of lithium chloride of a strength of two per cent. connected with the positive pole, the circuit is closed by a second warm bath containing a dilute solution of common salt in which the patient immerses some other indifferent part of his body. Currents of 25 milliampères for 20 or 30 minutes are used. Dr. Heyerdahl* has published some recent cases in which he carried out this treatment with good results. Dr. W. J. Morton of New York, has published a valuable treatise on the subject of cataphoresis dealing fully with its history, and its applications in medicine, surgery and dentistry† which should be consulted by those wishing to go deeply into the question.

126. **Death from electric shock.**—The fatal effects of powerful currents is probably due to stoppage of the

* "Tidsskrift for den Norske lœge forening," Kristiania, May 15, 1899.

† "Cataphoresis or Electric Medicamental Diffusion," New York, 1898.

action of the heart, the tracings (figs. 66, 67) show the results in some experiments upon cats under chloroform. In the first is seen the rapid fall of blood-pressure to zero after the passage of a current of half an ampère through the thorax ; while a current of the same magnitude through the skull produced a trifling effect, which is seen in the first part of the same tracing. In fig. 67 is seen the secondary effect upon respiration

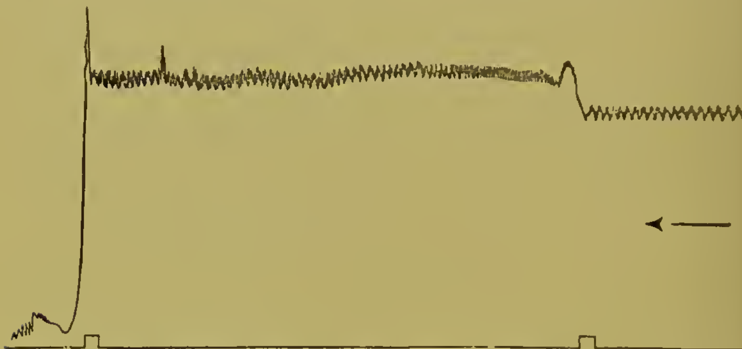


FIG. 66.—Blood-pressure tracing, showing effect of electric shock through skull and through thorax of a cat.

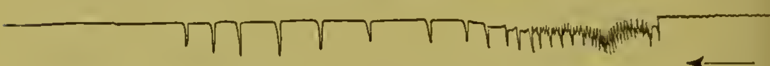


FIG. 67.—Tracing of respirations at first rapid, then slowing and stopping, after electric shock, and secondary to failure of the circulation.

caused by the failure of the blood supply in the respiratory centre. These tracings were taken during some experiments with the direct current. Oliver has more recently published tracings showing that with alternating currents the results are similar. To cause death the current must have a certain minimal value, and must traverse a vital organ, the heart being the most susceptible.

The views of D'Arsonval are that electricity proves fatal by primary arrest of respiration, and that the victims of shock can be resuscitated by artificial respiration. Prevost and Battelli have shown that death may be caused in either of these ways, the heart failing first in some cases and the respiration in others. Artificial respiration is important in the latter class, but of no use in the former. In the absence of direct observations the minimum fatal current for human beings may be estimated at about one half to one ampère. The most common path of the discharge is from one conductor to earth through the body, but the current may also pass directly from the body to the other conductor of the system. In the first case the point of exit is generally by the feet. Burns of the skin should always be looked for at the points of entry and of exit; they may be severe or slight. When the current goes to earth through the feet these may not show signs of burning if the foot covering is damp. The severity of the burns is proportional to the duration of the discharge. Most of the fatal accidents have been with potentials above one thousand volts. The body may carry a current sufficient to produce extensive burning at the points of contact, without causing death, this may even be the case when the current has fairly traversed the trunk. In a recent accident in London two men were concerned and the current passed from the conductor to the first and from him through the second to earth. The first man survived though the second was killed. The relative danger of alternating and direct currents is not decided; there is probably no great difference.

127. **Thermal effects.**—With the small currents used in medicine there is no appreciable heating of the

tissues. A slight warmth can be felt over a nævus during its electrolysis. In cases where death has been caused by the passage through the body of the powerful currents used for electric lighting, well marked signs of the production of heat have been observed *post-mortem* (see preceding paragraph).

128. **Electrical organs.**—The electrical organs of many fishes (electric eel, torpedo) may be briefly noticed in this chapter. They consist of lobes of a honeycomb-like structure, usually developing in a similar way to muscle, and supplied freely with nerves which terminate in the cells of the honeycomb in expansions something like those of muscle end-plates; irritation of their nerves causes an electrical discharge. It appears that they may have become specialised and developed from ordinary voluntary muscle, for the sake of utilising the electrical current of action, and that the structural changes are associated with the development of this portion of the muscular mechanism at the expense of its strictly motor powers. The chemical examination of the electrical organs seem to show that the products of their activity are very similar to those of active muscle, CO_2 and an acid reaction being produced.

Du Bois Reymond showed long since that muscular contraction always yields a current which can be measured by a galvanometer, and Waller has lately shown a method of demonstrating in the human subject that there is an electric current produced by the heart's beat, and that it can be led off to a galvanometer by wires from the two hands. It may be that the peculiar powers of electric fishes have grown up from the electrical current of action common to all contracting muscle, but it is difficult to trace the intermediate steps

in the scale of development. The skate has an electrical organ in its tail which is not able to give strong shocks, although it can deflect a galvanometer.

129. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of a magnet. Lord Crawford (then Lord Lindsay) and Mr. Cromwell F. Varley, with the help of an enormous electro-magnet, belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But in discussing these experiments in an address delivered at the Midland Institute at Birmingham,* in October, 1883, Sir William Thomson came to the conclusion that it is just possible that there may be a magnetic sense, and indeed a committee of the Society for Psychical Research,† who examined a large number of persons by placing their heads near the poles of an electro-magnet, found three who were sensitive and were able to say when the current was on or off. One of these persons was examined later by Prof. W. F. Barrett,‡ who found that when he was suffering from neuralgic pain, it became intensified by the presence of a powerful magnet.

In some recent experiments conducted with very powerful electro-magnets by Dr. Peterson and Mr. Kennelly in Edison's Laboratory, the results were entirely negative as the following extracts show. The subject placed his head between the poles of a large electro-magnet, which could be excited from a dynamo-machine. They reported as follows:—

"The armature of a dynamo was removed, leaving a

* *Nature*, vol. xxix., p. 438.

† *Proc. Soc. Psychical Research*, part iii.

‡ *Nature*, vol. xxix., p. 476.

space between the poles of its field magnet. This field magnet was then excited from another dynamo, driven by steam power and the subject introduced his head into the space between the poles. The weight of the electro-magnet was over 5000 pounds, and the intensity of the magnetic field produced within the polar cavity after removal of the armature, though not uniform, may be estimated at a mean of 2500 C.G.S. lines to the square centimetre. A long board was placed upon the base plate leading into this polar cavity, and the subject experimented upon lay on his back upon the board with his head and shoulders in the cavity between the poles, and exposed thus to the full influence of the magnetic field. A switch so nearly silent in action as to be inaudible to the subject was arranged to close and open the exciting current circuit through the field coils. On closing the switch nearly the full magnetic intensity would be active and permeating the head within practically one second. Similarly on opening the switch, almost the whole intensity would diappear in about one second."

"Five men, ourselves among the number were, subjected to trial. One case described will describe all."

"The subject lay back upon the board and concentrated his attention upon his sensations. His right wrist was extended and was grasped by one observer, who took, sphygmographic tracings of the pulse. A second observer placed a hand on his chest to observe any irregularity that might occur in respiration. A third observer, in view of these two, but unseen by the subject of the experiment, opened and closed the switch that excited and released the field, signalling to the first two observers as he did so. The strong magnetic influence was therefore turned on or off at will, and

without the knowledge of the subject. Several sphygmographic tracings were taken in each of our subjects, and in one the knee-jerk was tested continuously."

"The sphygmographic tracings taken during the *séance* show no change in regularity, in spite of the making and breaking of the enormous magnetic influence during its registration. The respirations were not changed in the least. The knee-jerk also presented absolutely no change. As to common sensations, there were none that could be attributed to the magnetic influence, and the subject could not discover when or whether the field had been excited. The testimony of all five subjects was alike."

"No change could be seen in the circulation in the web of a frog's foot when this was placed between the poles of a large electro-magnet, and no effect was perceptible in a dog which had been confined for five hours in a strong magnetic field."

Experiments were also tried with another magnetic arrangement, in which the magnetism was reversed 280 times a second, as follows:—

"A large coil of stout, cotton-covered copper wire, about 30 cm. high, and 25 cm. internal diameter, composed of nearly 2000 turns, and weighing about 70 kilogrammes, was supported horizontally in such a manner that the head of the subject experimented upon could be freely introduced within the coil, and subjected to the electro-magnetic field created there by passing a current through the wire. The resistance of the coil was 10 ohms, and its inductance 0·73 henry. An alternating electromotive force of 1200 volts, making 140 cycles, or 280 alternations to the second, was connected with this coil, the current supplied being 1·85 ampères. The magnetic field in the coil would thus be reversed

280 times to the second. Each of the authors acted as subjects in the experiments, permitting the 1200 volt alternating current to be made and broken frequently in the huge magnetic coil surrounding his head. No effect whatever was experienced. The coil itself hummed with the current, and a strip of sheet iron held in the cavity of the coil, but not touching it, vibrated perceptibly in the hand and gave a distinct, loud sound, which was determined to be middle C of the musical scale."

"The authors conclude that the human organism is in no wise appreciably affected by the most powerful magnets known to modern science; that neither direct nor reversed magnetism exerts any perceptible influence upon the iron contained in the blood, upon the circulation, upon ciliary or protoplasmic movements, upon sensory or motor nerves, or upon the brain."*

It need hardly be pointed out that the phenomena of so-called "animal magnetism" have absolutely nothing to do with magnetism whatever. Moreover, the ordinary magnets used in medicine, and credited with wonderful powers, have a purely suggestive or psychic effect, and would in all probability be quite as useful if made of wood.

* Read before the American Electro-Therapeutical Association, 1892, reprinted with illustrations, in the *English Electrical Review*, August 18, 1893.

CHAPTER VIII.

Diagnosis.

Electrical testing. The motor points. Relation of spinal nerve-roots to muscles. Morbid changes in the electrical reactions. The reaction of degeneration. The sensory nerves. Nerves of the special senses. The auditory nerve.

130. **Electrical testing of nerves and muscles.**—The examination of the electrical reactions of the muscles in cases of paralysis is a very important part of medical electricity. Even those who are indifferent to the therapeutic actions of electricity are accustomed to attach importance to the electrical reactions as an aid to diagnosis.

An electrical test often gives distinct evidence in cases where without it one could only guess at the morbid condition of the affected parts. The following history affords a useful instance of its value. A patient had an accident with broken glass, cutting himself in four places; as the ulnar nerve showed signs of injury the wounds were carefully examined. In two of them the nerve was found to be divided and was sutured. In the other two wounds the nerve could not be seen, and it was thought to have escaped injury at these points. No electrical test was made at the time. Some weeks later the patient was referred to me for examination as the limb remained paralysed. In my report I stated that the nerve had undoubtedly been divided in a third place, namely, in the uppermost wound, which was above the elbow. An operation was accordingly per-

formed, the nerve was found to be divided and it was joined at that point. Some time later I saw the case again and reported that the nerve was in process of repair, and wanted only time and electrical treatment to recover its functions. After this the patient remained for some time with but slight signs of improvement, and a further exploratory incision was made to put aside all doubts as to the existence of re-union of the nerve. At the operation the electrical testing was vindicated by the discovery of a proper re-union of the ends of the nerve. With time the patient made a good recovery.

Electrical testing depends upon the fact that changes may appear in the normal reactions as a result of disease or injury. In the last chapter we considered the behaviour of normal muscle to the current of the induction coil, and to the make and break of a current from a battery of galvanic cells, and in this chapter the changes due to disease will be considered, together with the practical details of testing. As there may be changes in the behaviour of the muscle to both the coil and the cells, both forms of stimulus are used in the electrical examination of a muscle. The testing is usually a testing of the contractility of the muscles and the active electrode is applied to the muscle itself, at or near to its *motor point*. The nerves may also be tested to determine their power of conducting motor impulses, their conductivity being shown by the movements of the muscles to which they may be distributed. Sensory nerves are also tested and their condition inferred from the responses of the patient, but it is to the muscles that the testing electrode is generally applied as the state of the motor nerves is mainly deduced from the results shown by the muscular contractions.

In testing a muscle the electrodes required are the indifferent electrode (fig. 40) and the electrode with "closing" key (fig. 38). The former is to be placed over any convenient and remote part of the body, thus the patient may hold it against his chest, or it may be slipped down the back of the neck so as to be held in place by the pressure of the clothing, or, with a patient lying down it can be placed beneath the hips, or finally, if the patient is lying on his face it may be placed over the sacrum and held there by an assistant. In any case it must touch the skin with even and firm pressure throughout the process of testing. Both the electrodes and the surface of the body concerned must be well moistened with warm water or salt and water; and the more thoroughly this is done the more satisfactory will the testing be Salt and water lowers the resistance of the skin better than plain water, but its use has the drawback that it shows more tendency to corrode the electrodes. Plain hot water is therefore the best medium.

In testing the intrinsic muscles of the hands and feet, and with a few other muscles, as for example the deltoid, it may be convenient to apply both electrodes to the skin over the part tested in such a way as to cause the current to pass right through the part, thus the interossei are very conveniently tested with the indifferent electrode under the palm or sole and the active electrode on the dorsal aspect of the hand or foot.

Again for testing the muscles of the legs a very good position is for the patient to lie prone, with the indifferent electrode held by an assistant over the lumbar spine, the leg to be tested being flexed and supported vertically in the left hand. In this position all the leg muscles can be reached easily, and the foot is free to move in

any direction in response to the contractions of the muscles as they are tested. The left hand which holds and supports the ankle is well placed for feeling the movements of the tendons.

The active electrode or testing electrode should be of small surface, one which is three-quarters of an inch in diameter is good.

131. **The motor points.**—These are points to which the testing electrode should be applied in order to set up a contraction most easily in the subjacent muscle, or they are points at which motor nerve trunks can be easily reached. They represent positions at which a maximum effect can be produced by a given current, and a good knowledge of the motor points enables one to carry out a test with comparatively weak currents, and therefore with the least amount of discomfort to the patient. Many diagrams of the motor points have been prepared, most of them being based upon Von Ziemssen's plates (see Plates I. to VI. at the end of this volume).

Von Ziemssen prepared his plates by exploration of the surface with a testing electrode, and marking the points as they were found. He found by dissections on the dead body that the excitable points corresponded to points at which the main nerve supply entered the muscle.

It should be borne in mind that the motor points are not quite constant for different individuals, their exact place varying a little in different cases, but not so greatly as to diminish the value of knowing their positions. In actual practice the best position of the electrode can be readily found by experiment, by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the

contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a great deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is much more difficult than of the superficial layer, indeed in the case of some of the deep muscles it is almost impossible to produce satisfactory evidence of a contraction limited to the muscle sought, for the diffusion of the current will throw into action the neighbouring superficial muscles and so obscure the result. It is very important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen; the muscles must be lax, the limb should be supported by the hand of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is easily able to throw the muscle into contraction and to apply it only for a very brief moment at a time, in this way the patient will be least worried, and the process of testing will be sooner over. It is well always to try the strength of the current on oneself before touching the patient.

It is assumed that the action of the individual muscles is known, so that when a contraction is produced, it can be referred to its proper muscle. The actions of the muscles were elaborately studied by Duchenne, and he has described them at great length in his "Physiologie des Mouvements." Besides watching for and seeing the movement produced by the contracting muscle, one may often feel a weak contraction by placing the hand over the tendons lightly, or one may see or feel movements of the body of the muscle itself when they are too feeble to move the bone to which the muscle is attached.

The subjoined table of the points at which certain

nerves may be conveniently stimulated will be of service, and Plates I. to VI. which show the motor points must be continually referred to until they are known by heart. The areas of skin which are served by the several cutaneous nerves should also be studied. Heiberg's "Atlas of the Cutaneous Nerves," translated by Dr. Wagstaffe,* has some useful coloured outlines of these areas of distribution. Prof. Flower's "Atlas" may also be referred to. (See Plates VII. to IX., after Flower and Ranney). Brodie's "Dissections Illustrated" is also useful.

Points favourable for the testing of nerves:—

In the upper limb:—

1. *The median*, along the inner border of biceps, and at the bend of the elbow.
2. *The ulnar*, in the groove between the internal condyle and the olecranon.
3. *The musculo-spiral*, at the point where it emerges from the triceps; namely, on the outer side of the upper arm about the junction of the middle and lower thirds.
4. *The musculo-cutaneous*, between the biceps and coraco-brachialis.
5. The long thoracic (serratus magnus) on the inner wall of the axilla.
6. "At a spot one inch above the clavicle, and a little externally to the posterior border of the sterno-mastoid, immediately in front of the transverse process of the sixth cervical vertebra, a simultaneous contraction can be produced in the deltoid, biceps, coraco-brachialis, brachialis anticus and supinator longus." This point has been called

* Bailliere, Tindall and Cox.

the *supra-clavicular point* of Erb. It is a motor point for the fifth and sixth cervical roots before they reach the brachial plexus.

In the lower limb:—

7. *The anterior crural*, in the fold of the groin just outside the femoral artery.
8. *The sciatic*, just below the gluteal fold at the back of the thigh.
9. *The internal popliteal nerve*, in the popliteal space, and to the inner side of the tendo Achillis.
10. *The peroneal*, just above the head of the fibula, beside the biceps tendon.

In the face:—

11. *The facial*, through the cartilage of the lower surface of the meatus auditorius. Its chief ramifications can be reached where they emerge from the parotid gland. Erb chooses for stimulation three main branches of the facial: (*a*) for muscles above palpebral aperature; (*b*) for muscles in front of upper jaw, between the orbit and the mouth; (*c*) for muscles of the lower jaw. He tests each of these in two places, first at points just in front of the ear, and secondly for (*a*) at the temple, for (*b*) at anterior extremity of zygomatic bone near its lower border, for (*c*) at the middle of the inferior border of the horizontal ramus of the lower jaw.
12. *The fifth*, at the supra-orbital foramen, at the infra-orbital foramen, at the foramen mentale, on the side of the tongue.

In the neck:—

13. *The spinal accessory*, at the top of the supra-clavicular triangle, where the nerve pierces the sterno-mastoid.

14. *The phrenic*, on the outer edge of the lower part of the sterno-mastoid.
15. *The hypoglossal*, along the upper border of the great cornu of the hyoid bone.
16. *The recurrent laryngeal*, along the outer border of the trachea.
17. *The pneumogastric* and *glosso-pharyngeal* along the track of the carotid artery just below the angle of the jaw.

132. **Relation of spinal nerve roots to muscles.** —Frequently it happens that paralysis affects a group of muscles; in these cases much light may be thrown upon the diagnosis if it is possible to trace back the nerve supply of the affected muscles to their spinal roots. This is not always easy, particularly when the nerve trunks pass through a plexus like the brachial plexus on their way from the cord to the muscles. For example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand, and a lesion of the eighth cervical and first dorsal roots on the other; in the latter case the whole of the thenar and hypothenar eminences and all the lumbricales and interossei would be involved, in the former case many of these muscles would escape, namely, the hypothenar, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of the flexor brevis, all of which are supplied by the ulnar nerve.

A paper published in *Brain*, 1881, by Dr. Ferrier, gives a tabular statement of the more important spinal nerve roots, with the muscles supplied by each. As it is likely to be of great value in electrical diagnosis we reproduce it here, as modified by Dr. De Watteville, *Lancet*, July, 14, 1883.

Nerve roots:—

4th cervical.—Deltoid, rhomboids, spinati, biceps; brachialis anticus, supinator longus; extensors of hand.

5th cervical.—Deltoid (clavicular portion), biceps; brachialis anticus, serratus magnus, supinator longus; extensors of hand.

6th cervical.—Latissimus dorsi, pectoralis major, serratus magnus, pronators, triceps.

7th cervical.—Teres minor, latissimus dorsi, subscapularis, pectoralis minor, flexors of hand, triceps.

8th cervical.—Flexors of wrist and fingers, muscles of hand, extensors of wrist and fingers, triceps.

1st dorsal.—Muscles of hand (thenar, hypothenar, interossei).

3rd lumbar.—Ilio-psoas, sartorius, adductors, extensor cruris.

4th lumbar—Extensor femoris et cruris; peroneus longus; adductors.

5th lumbar.—Flexors and extensors of toes—tibial, sural, and peroneal muscles, extensors and rotators of thigh, hamstrings.

1st sacral.—Calf, hamstrings, long flexor of great toe, intrinsic muscles of foot.

2nd sacral.—Intrinsic muscles of foot.

Reference to the paper of Dr. Ferrier will show that in his table the function of each nerve root is expressed in terms of the movements produced, and not in terms of the muscles concerned in producing the movements.

Dr. Herringham* has also tabulated as follows the results of numerous dissections of the brachial plexus in new-born infants.

* *Proc. Roy. Soc.*, March, 1866.

Usual nerve supply :—

3rd, 4th and 5th cervical.—Levator anguli scapulæ.

5th.—Rhomboids.

5th or 5th and 6th cervical.—Supraspinatus, infraspinatus, teres minor.

5th and 6th cervical.—Subscapularis, deltoid, biceps, brachialis anticus.

6th cervical.—Teres major, pronator radii teres, flexor carpi radialis. Supinator longus and brevis. Superficial thenar muscles.

5th, 6th and 7th cervical.—Serratus magnus.

6th or 7th cervical.—Extensores carpi radiales.

7th cervical.—Coracobrachialis, latissimus dorsi, extensors at back of forearm, outer head of triceps.

7th and 8th cervical.—Inner head of triceps.

7th, 8th and 1st dorsal.—Flexor sublimis and profundus, flexor carpi ulnaris, flexor longus pollicis, and pronator quadratus.

8th cervical.—Long head of triceps, hypothenar muscles, interossei, deep thenar muscles.

The *pectoralis major* from 6th, 7th, 8th and 1st dorsal.

The *pectoralis minor* from 7th, 8th and 1st dorsal.

133. **Practical testing.**—When a fair degree of skill in finding the motor points has been acquired, the chief difficulties of testing the reactions of a patient's muscles will disappear. Nothing is so useful as to practice frequently upon one's own muscles, and the dislike which many people have to applying currents to their own persons is unreasonable, for a current which is strong enough to provoke contraction in healthy muscles is not really painful and there is no way of learning the motor points like a practical experiment upon one's own muscles. Half an hour spent in picking out one's own motor points, and in observing the relative sensi-

tiveness of the skin in different parts of the body, and in noting the effect of a thorough moistening of the skin before applying the testing current will well repay a beginner in electrical testing.

Another small point of importance is to make a rule of applying the current to one's self at the commencement of a test. If this is done the patient feels reassured, and the chance of the current being applied too strongly is decidedly lessened. The easiest method is as follows :—

Place the indifferent electrode in position on the patient and moisten the skin of the part to be tested, then grasp that part in the left hand, and, taking the testing electrode in the right apply it to the back of the left hand which is holding the patient; the current then, on closing the key, will pass to the patient through the hand of the operator, who will be able to judge of the strength of the current by the sensation or the muscular contraction produced, and will be able to adjust it accordingly. Always commence testing with the coil, and use the cells later. There is no need to push the coil current too greatly. In testing with the cells begin with about sixteen cells for the limbs, or half that number for the face, and apply the electrode, which should be made the kathode. Note whether a closing contraction is visible or not ; if not, increase the number of cells in circuit until it appears, and take readings of the galvanometer; when the first closing contraction becomes visible note the effect of moving the electrode, and find the most effective spot for stimulating the muscle, then compare the A.C.C. with K.C.C., and take especial notice of the nature of the contraction, to see whether it be quick or sluggish ; compare the contractions obtained by direct stimulation of the muscle

Report of Electrical Reactions.

Name—T. B. S. *Age*—32 *Date*—Oct. 4, 1894.

Region examined—Left arm and forearm. *Diagnosis*—Neuritis of musculo-spiral N.

Muscles.	Induction Coil.	Battery.	Excitability.	Remarks.
Triceps.	Natural.	Natural.	Natural.	A tender point over musculo-spiral trunk in middle of upper arm.
Supinator longus.	Decreased but not lost.	Sluggish.	Increased.	
Ext. carpi rad. longior.	,,	,,	,,	Injury three weeks before.
,, ,, ,, *brevior.*	,,	,,	,,	Partial reaction of degeneration in all these muscles except triceps.
,, ,, *ulnaris.*	,,	,,	,,	
,, *comm digit.*	,,	,,	,,	*Supinator brevis* not tested.
,, *ossis metacarpi poll.*	,,	,,	,,	
,, *primi internod.* ,,	,,	,,	,,	Sensation impaired over extensor aspect of forearm.
,, *secundi internod.* ,,	,,	,,	,,	
,, *indicis.*	,,	,,	,,	Voluntary power much impaired. Wrist drop.
,, *minimi digiti.*	,,	,,	,,	The other muscles of the limb quite normal.

Treatment—Electricity (induction coil). *Prognosis*—Favourable.

with the effects of stimulating the nerve trunks. Lastly, test sensation with the induction coil current, and note the results upon a table like that given in the accompanying leaf.

Compare the reactions of the healthy side with those of the affected side.

When the affected parts can be compared with the corresponding region on the opposite and sound side of the body, it is not difficult to perceive changes in the electrical reactions. When the disease is bilateral this is not so simple, and one must depend to a certain extent upon previous experience, and upon comparisons with one's own reactions; but, wherever possible the comparison of the affected muscles with their fellows of the opposite side of the body is a matter of the first importance.

134. **Changes in the electrical reactions.**—The changes which may be found in the reactions as the result of disease or injury are classified as follows:—

1. Changes in the amount or *quantity* of response to stimuli, the character or *quality* of the reactions not being otherwise changed.

This includes simple increase of excitability and simple decrease of excitability to coil and cells, changes which are usually spoken of as *quantitative* changes.

2. Changes in the nature or *quality* of the reactions or *qualitative* changes. These are the reactions of degeneration both complete and partial.
3. The condition of total loss of all visible contractions both to coil and to cells must also be considered. It has a very definite significance, but its interpretation is not always the same, though it is always a grave sign. (See also § 140).

135. **Quantitative changes.**—(*a*). *Increased or de-*

creased irritability to coil currents.—Before forming a diagnosis of increase or decrease of excitability it is necessary to keep in mind the importance of measuring the resistance of the patient at the same time, because without the galvanometer it is not easy to known how much of the result depends upon altered resistance and how much on altered excitability.

In unilateral disease increased or decreased excitability is shown by differences in the behaviour of the two sides. If the normal side be first tested an increase of excitability will be shown on the affected side if the minimal contraction shows itself with a lesser current. If both sides are affected, then an increased excitability is inferred if the minimal stimulus is seen with currents which are weaker than those which the operator has taught himself to recognise as usual in healthy people.

(*b*). *Increased or decreased excitability to battery current.*—Simple increase of excitability is shown by the development of KCC with a smaller galvanometer deflection than usual, by the ready production of duration tetanus, and generally by the easier production of all the contractions.

Simple diminution of excitability is shown by increased difficulty in the production of all the contractions. A stage may be reached when they can be obtained only with strong currents, and finally all reaction may disappear ; excitability is then said to be lost or abolished.

Increased excitability of the nerves and muscles is not very common, when it does occur it represents phases of irritation, and therefore it may be seen in the early stages of several disorders (such as tabes, chronic myelitis, hemiplegia) where at a later period the reactions become diminished.

Simple diminished excitability occurs in many old-standing nervous diseases, in myopathic muscular atrophies, in some cases of peripheral neuritis, and generally in wasted muscles.

The recognition of increased or decreased irritability is easy when the increase or decrease is considerable, but to diagnose slight increase or slight decrease demands the greatest care, as there are many disturbing factors to be guarded against. With the battery current a careful attention to galvanometer readings is the best guide, but even then one has to consider the differences which may depend upon the place of the testing electrode, for a slight movement away from the motor point will make the current less effective, and so simulate a decrease of irritability and again unequal pressure of the electrode on the two sides may cause an apparent difference in irritability, for with increased pressure the electrode is pushed nearer to the nerve or muscle owing to the elastic yielding of the subcutaneous tissue. Again the resistance of the skin may vary greatly during a test, and it usually falls while the testing is in progress, and this complicates matters. With induction coil testing there is no galvanometric means of checking off the strength of the currents employed, and one has to fall back upon estimations of the voltage given by the coil. This leaves an opening for errors due to differences in resistance. Sometimes the skin resistance in a paralysed limb may be greatly increased, through alterations in the texture of the skin which covers it. Consequently when there is a question of carefully determining small decreases or increases of irritability, measurements of the resistance must first be taken as carefully as possible, and the situation of the electrode upon the skin must be carefully marked.

The diagnostic value of small quantitative changes is not very great, so happily their determination is not of the first importance.

The electrical properties of the testing circuit have also a decided influence upon the apparent excitability of nerve and muscle, and this introduces fresh disturbing factors when the results of testing with one apparatus are compared with those of a different one. Dr. Dubois in a very instructive paper* on the physiological effects of the continuous current has clearly shown that the presence of resistances in the testing circuit lowers the stimulating effect of a current of given magnitude, thus a current of three milliampères passing through a circuit composed of the body and of a resistance is less effective in causing a muscular contraction than a current of three milliampères traversing the body in a circuit without any other external resistance, and he further goes on to prove that any increase in the self-induction of a testing circuit acts in the same way and lowers the stimulating effect of the current by retarding the rate of growth of the current at the moment of closure, which is the moment also of testing.

A stimulus is effective in proportion to the suddenness with which the current rises to its maximum, and the greater the self induction of the circuit the slower this rise becomes. The presence in the circuit of a milliampere meter, which is an instrument of high self-induction, will therefore tend to increase the magnitude of the current required to cause contraction in the muscles and this will be more marked with delicate galvanometers wound with many turns of wire than it will be with smaller instruments. By shunting the galvanometer (§ 86) or better still by the use of a

* *Arch. d'électricité médicale*, 1898, page 1.

condenser of large capacity (one microfarad) (§ 33) connected in shunt to the galvanometer terminals, the testing current may be made more effective and the minimal contractions obtained with smaller currents. The self-induction of resistances interposed in the circuit will equally influence the results of testing with coil currents.

136. **Qualitative changes—The reaction of degeneration.**—This term was introduced to signify the altered electrical reactions which occur in the nerves and muscles under certain definite morbid conditions, the peculiar feature being that the change is not only a quantitative one, but also a qualitative one; that is to say, there is an alteration in the quality of the response which the degenerate muscles make to the battery current. KCC often becomes relatively less easily elicited than ACC, though this is not invariably the case, and the contraction provoked is a slow and sluggish one, differing greatly from the very rapid contraction given by a normal healthy muscle.

This reaction of degeneration (usually symbolised by the abbreviation RD) is of very great importance. Its discovery and development arose from an observation of Baierlacher in 1859, that the muscles in a case of facial paralysis did not respond to the coil, but reacted with unusual force to the battery current, and to Erb's careful study of the symptom then first made known, we owe the most important fact connected with electricity in medical diagnosis.

The investigation of the reaction of degeneration has been pursued both clinically and experimentally, and its value consists in the fact that when it is present we can diagnose a break in the nervous link which connects the end plate of the muscle with its "nucleus of

origin " in the grey matter of the anterior cornu of the spinal cord; the lesion therefore must either be in the grey matter of the anterior horn in the cells from which the nerve fibre starts, or in the course of the nerve fibre from there to the muscle. The reaction of degeneration does not follow central nerve lesions which are wholly above the spinal ganglion cell whence the nerve fibre springs, nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

In RD the irritability of the nerve disappears entirely, and therefore stimulation of it has no effect, the muscle on the other hand retains its irritability to the battery but not to the coil current, that is to say its irritability is still present for certain stimuli. It does not react to the interrupted current of an induction coil, but it reacts to a mechanical shock and to a battery current slowly made and interrupted. If the battery current be made and broken rapidly by an automatic vibrator, the muscle will not respond to it, or it may respond once at the first closing of the circuit. A curarised muscle will still react to coil currents, though not so readily as a normal muscle, therefore the total loss of "faradic" irritability in a muscle showing the reaction of degeneration signifies something more than a torpor of the intramuscular nerve endings, it means that a trophic change has occurred in the muscle protoplasm, and further evidence of the change is seen in the frequent production of ACC more easily than KCC. This alteration of the relative effect of the poles, is not an important part of the reaction of degeneration, for it is not constantly present. Another important alteration is that the irritability of the muscle to the battery current may be greater than in health, strong contractions

being set up in the affected muscles by currents which are too weak to produce any visible movement in neighbouring healthy muscles.

It is only in fairly recent cases that the phase of exaltation of muscular irritability is manifested, and in most cases of RD, that is, of course, if recovery does not set in, the later stages show a progressive loss of irritability of the muscle.

Erb's definition of the reaction of degeneration is the following:—"It is characterised by the diminution and loss of faradic excitability in both nerves and muscles, whilst the galvanic excitability of the latter remains unimpaired, is sometimes notably increased and always undergoes definite qualitative modifications."

137. **The course of the reaction of degeneration.**—At first for two or three days after the onset of the lesion there will be in the *nerve* a progressive lowering of all electrical excitability, and after this the irritability of the nerve will be completely abolished and will remain so unless recovery takes place; in that case the return of motor power may precede the return of electrical irritability.

In the *muscle* the reaction to coil currents runs the same course as in the nerve. To battery currents, on the other hand, there is at first a progressive lowering of excitability, but by the end of a week this is replaced by an increase of excitability to a point much above the normal, with sluggishness of contraction and sometimes with ACC > KCC; after a period of three, six, or eight weeks, diminution of excitability sets in, and the diminution is progressive until at last it may disappear entirely.

In cases which recover it often happens that the power of voluntary movement will return some little

time before the response to electrical stimuli, but in other cases both may return simultaneously.

When a nerve has been completely divided the changes which occur are as follows:—

1. A sudden loss of voluntary power in the muscles supplied by the divided nerve.

2. Arrested conductivity of the nerve—therefore abolition of excitability in the muscles supplied from below the wound, when both electrodes are placed on or near the nerve trunk below the seat of injury.

3. For two or three days, sometimes only for forty-eight hours, some trace of contractility to coil currents remains present in the muscles when the electrodes are applied on the distal side of the section or on the bodies of the muscles. The disappearance of this reaction shows degeneration and loss of irritability extending down the intra-muscular nerve fibres to the end plates.

4. Increased "galvanic" irritability accompanied by a relative increase of anodal excitability. The anodal closing contraction (ACC) often approaching in amplitude and ultimately exceeding (about the sixth or seventh day) the cathodal closing contraction (KCC). The electrodes are applied, one on an indifferent part of the body, and the other on the muscle, and the direction of the current is alternated on purpose to compare the amplitude of the contractions produced. The current is conveyed, not by the nerve, the continuity of which is severed, but by all the tissues intervening between the two electrodes.

5. As the muscle degenerates its irritability steadily declines. The final disappearance of all irritability may not take place for many weeks, or months, or years.

6. If union of the divided nerve takes place, voluntary movement in the muscles again becomes possible; muscular regeneration commences; the electrical reactions gradually return and the irritability again very gradually rises to its former condition.

Such is a review of the typical electrical reactions of nerve and muscle after complete severance of a nerve, and these reactions modified in various ways, by the amount of destruction to the motor centres or cells, or the conducting nerve fibres, are characteristic of the several nervous diseases where qualitative changes in the electrical reactions are to be observed.

Professor Erb is careful to remind his readers that various deviations from the typical form of the reaction of degeneration may be met with. He says: "You must not expect to find in every pathological condition so great a uniformity in the course of these modifications as is to be met with in experiment, or in a simple traumatic lesion of the nerves; this does not often occur in disease, where many deviations may be caused by the nature of the injury, different affections of trophic influences, occasional improvement, or new elements of disturbance following one upon another; and one is not warranted in concluding from some irregularity, such as presents itself in long-standing cases, that one has discovered some fresh anomaly. The time at which repair takes place determines great differences in the general manifestation of the reaction of degeneration. If this happens early the nerve may be endowed with galvanic and faradic excitability while the changes of the muscle are at their height, these latter cannot be reformed so quickly, and require for the purpose some lapse of time. It may happen then, that when the nerve is excited the muscle responds with normal contractions, but still

when stimulated directly exhibits the reaction of degeneration. But if repair sets in very late, it may be that the muscular excitability is already greatly diminished when the excitability of the nerve begins to be slowly restored. There is, therefore, an indefinite number of special cases, which nevertheless may be mastered by carefully attending to the conditions of time and other circumstances."

138. **Partial reaction of degeneration.**—This term is applied to cases in which some degree of contractility for coil currents is present although there is decided sluggishness of contraction of the muscle for the battery current.

Muscles having the partial reaction of degeneration may exist in a limb side by side with others showing the complete form, and other muscles may show other degrees of transition between the normal state and partial or complete degeneration, but the existence of such a condition as that in which the muscles show a reaction of degeneration, though connected to the central nervous system by a nerve still functional, or at least capable of conducting impulses to the muscle, makes it more than ever difficult to understand the exact meaning of the muscular changes which give rise to the phenomena of the reaction of degeneration. Erb especially insists that this partial form of RD may occur in cases of commencing recovery from complete reaction of degeneration, or it may be present at the commencement of an attack, and may be followed at a later period by the complete form in the same nervous and muscular structures.

The existence of "partial RD" makes it important in testing always to confirm the results of the coil test by the application of the battery current test. If partial

RD be present there is usually a perceptible alteration in the coil reactions, but this may be overlooked, and in that case conclusions drawn from the presence of coil reactions alone would seriously mislead.

139. **Conditions which lead to the reaction of degeneration.**—Briefly speaking RD follows damage in that region of the motor path to which Dr. Gowers has given the name of the "lower segment," that is to say, that part of the course of a motor fibre which commences at the motor ganglion cell of the nucleus of origin or of the anterior cornu, and is continued down as a nerve fibre to the motor end-plate beneath the sarcolemma of its muscle. It does not follow damage limited to the "upper segment," and in the lower segment a certain degree of severity in the damage is necessary to produce it. RD is found after division, destruction, or injury of motor nerve trunks, and after disease or injury affecting the ganglion cells of the anterior cornu cf the cord, or the corresponding nuclei of origin in the case of the cranial nerves. Under one or other of these morbid states can be grouped pressure palsies of all kinds, division or laceration of nerves, different forms of peripheral neuritis, poliomyelitis anterior both acute and chronic, muscular atrophies from disease in the spinal cord or in the nerves (but not atrophies of muscular origin), also acute and chronic myelitis, lead poisoning and diphtheritic paralysis. The reaction of degeneration is not found in the paralysis of cerebral disease (except when the implication of the nuclei of origin or of the nerve trunks of the cranial motor nerves produces a reaction of degeneration in the muscles which they supply) nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

The following history shows the value of the recognition of RD in a doubtful case. A woman fell down some stone steps and cut her head. She was picked up insensible and paralysed in one arm, and in this state was brought to the hospital. It was uncertain whether her paralysis was due to the head injury or not, and different people took different views of the case, but electrical testing showed RD in many muscles of the paralysed arm, thus proving that the paralysis was not due to the blow on the head, but to an injury to the brachial plexus caused by the fall. The question of an operation to explore the wound of the head could therefore be dismissed.

140. **Prognosis in the reaction of degeneration.** —" Other things "—that is the cause and nature of the disease—" being the same, the lesion is serious, the probable duration of the disease longer, the definite prospect of a cure more remote in proportion as the reaction of degeneration is developed and complete, and in proportion to the stage which it has reached" (Erb).

He instances the value of the symptom in the prognosis of simple facial palsy, distinguishing three forms. (1) *Mild*, electrical reactions normal, prognosis favourable, probable duration three weeks. (2) *Intermediate*, partial RD, duration one or two months. (3) *Serious*, complete RD, prognosis bad, duration three, six, nine months or longer.

At the same time he emphasizes the importance of the saving clause with which the quotation opens, insisting that it is not permitted to reason alike in all paralyses, without giving due weight to the importance of the lesion producing them, for instance the prospects of a case of facial palsy from caries of the petrous por-

tion of the temporal bone cannot be expected to resemble those where the mischief has been set up by a mere exposure to cold; and electrical reactions which are a guide to prognosis in cases of the latter type must not be forced into a similar interpretation for the former. There is an important remark of Dr. de Watteville's which may be quoted:—"It may not be unnecessary to guard the student against the error of looking upon the occurrence of alterations in the response of nerves and muscles as in itself indicative of irreparable mischief. On the contrary, RD is often of far more favourable prognosis than normal reactions, which we have already found to be consistent with absolutely incurable lesions, involving complete paralysis. Intractable spasms, tremors, or convulsions again are never accompanied by any notable disturbance, quantitative nor qualitative, of the electrical reactions."

To this may be added that the electrical test can only be used to obtain information as to a certain portion of the nervous system, namely, the lower segment, and also of the muscle at the time of making the test, and if inferences are to be drawn from the observations made it will be necessary for the observer to take many other circumstances into consideration, and it will rest with the observer to draw the correct inferences from his facts.

Among the practical points which continually arise in connection with the RD, perhaps none are more important than the giving of an answer to the question whether a nerve trunk is divided or only hurt. The question is one of the utmost importance, because the whole future conduct of the case rests upon the answer and it may be difficult to answer it because RD will

equally follow division and severe injury. Perhaps it will be useful to consider an actual case:—A barber on board ship was at work with a pair of scissors when the vessel gave a heavy roll and the patient accidentally plunged the scissors into his arm-pit. It bled a good deal and was bandaged up tightly and remained so for several days until the ship came into port. He was then found to have an extensive paralysis of the forearm and traumatic aneurysm of the axilla. I was asked to report on the paralysis and to state whether any nerves were divided or not. He showed RD in the ulnar and musculo-spiral areas. In the latter area one muscle, the triceps, did not show complete RD, for it retained its contractility to the coil in part, while in the ulnar area the paralysis was not absolute, the wasting was not extreme and sensation though impaired was not altogether lost. On these grounds the report was given that the musculo-spiral nerve was not severed, and that in all probability the ulnar had also escaped. His nerve trunks accordingly were not explored, and under treatment by electricity he made a gradual but complete recovery. His paralysis probably had been caused by the tight bandaging and not by the punctured wound.

Another case was one of gunshot wound of the lower half of the arm with extensor paralysis. He was examined electrically about five weeks after the accident, when healing of the extensive lacerated wound had made good progress. There was RD of all the extensors, but wasting was not extreme, the contractions were of very good volume and the sluggishness was not conspicuous. Judging that if the nerve had been completely severed the reaction of degeneration would have begun to enter the stage of decreased irritability, and

finding it to be not decreased an opinion was given that the trunk of the musculo-spiral had escaped. The later history of the case proved this opinion to have been correct.

Thus the diagnosis between severance of a nerve and serious injury without severance cannot be made with certainty by electrical testing, although a careful scrutiny of all the phenomena, motor, sensory, vasomotor and trophic will usually enable one to form a correct opinion.

Anything incomplete in the symptoms of paralysis, of anæsthesia and of wasting points to a non-severed nerve, and the progress of the symptoms in a case watched for a time will also throw light upon the question. The reactions will rapidly become degraded in total division, and all the symptoms will become worse, while in cases of injury without division the patient may show slight improvement from week to week.

Another common problem in practical testing is the following:—A nerve-trunk has been operated on and sutured; after the lapse of a certain period of time the case is sent for a report as to whether the sutured ends have become united, the patient being anxious owing to there being no return of voluntary power. Here, again, the mere testing of the muscles does not help much. Even in favourable cases the reaction of degeneration may show a general degradation in character even when sensation and voluntary power are returning steadily; indeed it is common to find loss of all reactions or the merest remnants of the RD in cases more than half recovered. One cannot expect normal reactions until late in the course of the case, and usually they return too late to be of much prognostic value. If

contractility to the coil returns early it is a good sign and foreshadows rapid recovery.

After operations for suture of divided nerves the chief need on the part of patient and surgeon is patience. Divided nerves are slow in recovery, especially if an interval has passed between division and re-union; reactions of normal quality are slow to re-appear, particularly when there is a long stretch of nerve between the wound and the muscle tested; the most distal muscles suffer the most, and regain power and reactions the latest. Even in a simple case of division of a nerve in a clean wound, and suture the same day, an interval of one hundred days may elapse before there is any return of power.

141. **Recent study of electrical reactions.**—In the *Bulletin Officiel de la Société d'Electrothérapie*, 1897, will be found two valuable papers on this subject the one by Doumer, the other by Huet. The former takes the line that the reaction of degeneration is best viewed as a combination of several alterations from the normal, each probably having its own special meaning, and he then proceeds to an analysis of the various conditions of the reaction in disease with the object of determining what may justly be inferred from each. He insists upon the difference between a nervous impulse and an electrical one, pointing out that an electrical impulse reaching a motor nerve fibre is first translated into a nervous impulse and then passes on in that form along the nerve and to the muscle. Further he argues that the nerve may fail either to effect the translation or to convey the translated impulse, or that the muscle receiving a proper impulse may fail to respond to it by a proper contraction.

Those who are familiar with electrical testing are well

aware of the fact that notable variations in degree are to be seen in the reaction of degeneration. Some of these are certainly due to a general degradation of the state of the muscle in cases of long standing, which makes the contractions more difficult to see, and deprives them of some of the sharpness of character which one might expect. Examples of this kind in which the RD can still be observed but which are not good cases for the demonstration of typical RD are common enough. The polar change with predominance of ACC over KCC is referred to by Professor Erb as one of the most constant phenomena in medicine, but in my experience and in that of others its appearance is so inconstant as to be absolutely without diagnostic value as a part of the reaction of degeneration. Again, the degree of sluggishness, or in other words the duration of the contraction produced in muscles by the closure of the current from the cells varies within wide limits; so that at times one may see a contraction so long and slow as to resemble a veritable peristalsis of unstriped muscle, while in other cases it is only after minute and oft repeated comparisons with sound muscles that one can at last determine whether the contraction to cells is or is not altered.

It is probable that the relative order of appearance of ACC and KCC may depend upon chance positions of the testing electrode. See § 116 last part and fig. 65 for the virtual polarity of parts around an electrode. Thus a positive electrode near to a motor point but not exactly over it might set up a virtual negative polarity at the motor point and vice versa.

142. **Duration tetanus.**—Closely associated with the reaction of degeneration one may notice a ready production of Duration Tetanus, that is to say the

persistence of a notable degree of contraction to the battery current so long as the circuit remains closed (§ 117). A small degree of contraction remainder is usual in all muscles during the time which lies between the closing and opening of the circuit of the cells, but ordinarily it is not perceptible to the eye with the currents commonly used in testing. If it becomes conspicuous it may signify a morbid change like that of RD; with which it is often though not always associated. The Myotonic reaction is something analogous and occurs in a rare condition called Thomsen's disease.

143. **Study of muscle contractions by the graphic method.**—The graphic method of recording tracings of muscular contractions deserves more attention. A certain amount of work has already been done in this way and an apparatus has been described by Radiguet with which the tracings may readily be taken. It is made by Chardin (7 Rue Linné, Paris) and consists of a combination of key electrode (§ 79) with a tambour for receiving the impulse and transmitting it to a revolving drum. What is wanted most is a long series of observations upon muscle contraction with tracings taken under varying conditions and combined with careful time tracings in order to collect facts upon which to found an analysis of the conditions under which variations occur. The latent period, the phase of contraction, and the phase of relaxation all need to be studied. So too the form of the electrical impulse requires study in conjunction with such tracings. The points referred to in § 135 make it probable that something might be learnt from a comparison of the effect upon contraction of circuits having self induction with that of circuits having condensers inserted in them to neutralise their self-induction.

Mendelssohn has applied the graphic method to the study of muscle curves, and has described modifications under the names of "curve of spastic muscle," "paralytic curve," "atrophic curve" and "degenerative curve." These though interesting are not yet sufficiently developed to have much diagnostic value. The "longitudinal reaction" described by Doumer in 1891 is the production of a sluggish contraction by anodal or cathodal closure (cells), the electrodes being so arranged as to allow the current to traverse the whole length of the muscle, the motor point not being considered.

It has been said that a sluggish contraction in a muscle is occasionally set up when the electrode is applied to a remote point of its nerve trunk; this contrasts with the loss of response of the nerve trunk which usually is associated with sluggish contraction in a muscle. It has also been said that the induction coil current applied to a motor point may set up a sluggish contraction instead of a tetanus. These are curiosities or errors of observation.

144. **Sensory nerves.**—There is but little to be said on the subject of alterations in the electrical reactions of sensory nerves. Simple increase of sensibility and simple decrease of sensibility can be detected, and apparently the degree of electrical sensibility corresponds rather with the degree of perception of pain than with that of perception of tactile sensations. This has been determined in diseases in which these two forms of sensibility are often affected in unequal degrees.

For investigating the electro-cutaneous sensibility the interrupted current must be employed, and it is as important to notice and take into consideration the amount of skin resistance, as it was in examining the

muscles, and in the absence of a suitable galvanometer, the sledge coil must be used, and the distance of secondary coil from primary must be noted and recorded. For testing the sensibility of the cutaneous nerves one may use a metallic brush for the active electrode and should not moisten the surface of the skin; or an electrode devised by Erb may be used. It consists (fig. 68) of a bundle of 400 metallic wires sheathed and var-

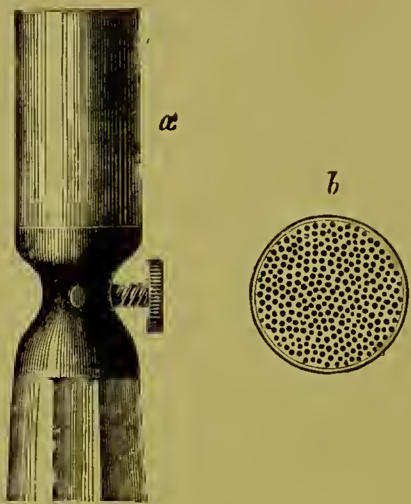


FIG. 68.—Cutaneous testing electrode. *a*. Side view. *b*. End view.

nished, enclosed in a vulcanite case of about two centimetres in diameter. At one end the wires are all put in metallic communication, and are attached to an ordinary electrode handle, the other end is polished, so that when applied to the skin it has the effect of a smooth surface. It covers an area of skin of about two centimetres in diameter, and into this the current enters in 400 parts. Thus a more regular action on the nume-

rous nerve terminations is secured, and with the interrupted current the degree of stimulus may be estimated for the first appearance of sensation, and for the first perception of pain. The following remarks* on the subject of estimating anæsthesia, are of great value in showing how easy it is to be misled in testing a patient for anæsthesia. "The patient should always be placed in such a position that it is impossible for him to see the hand of the surgeon, or the area which is under observation. He should not be allowed to move the finger or other part touched, for thereby the muscular sense comes to the aid, and falsifies observations. The impact of the instrument used should be very light, for a patient can frequently discern friction on an anæsthetic surface by means of vibrations carried by the tissues to surrounding healthy nerves. . . . I have often seen the sensory power of a presumably anæsthetic part tested by rubbing the part with the finger while the patient's eyes were averted, and almost always with the result that the stimulus was correctly perceived, and that a returning sense of touch was diagnosed by the investigator. Such a conclusion is entirely erroneous, for as Létiévant has pointed out, any person can perceive friction applied even to the finger of another person, if it be held between the bases of two of his own fingers, *i.e.*, the vibrations are conveyed to and appreciated by the nerves of the surrounding digits. How much more must this be so in the case of a divided median nerve when healthy nerves are present on part of the very finger to which the friction is applied. Friction should, therefore, never be used as a test of sensation, for the same reason the part which is being

* "Lectures on Injuries of Nerves," *Lancet*, June, 1887. A. A. Bowlby.

examined should never be pushed or thrust away from the position in which it lies."

St. John Brooks has drawn attention to the fact that in the hand the areas supplied by the different sensory nerves overlap considerably.

An ingenious method of testing the sensibility of a patient is to use one's own finger-tips as the electrode, for by proceeding in this way the operator has his own sensations as a guide, and can use them to check the patient's statements. If an opening and closing key, out of the patient's view, be included in the circuit the current can be turned off and on and the patient told to say when he feels this being done. A systematic examination of the different parts of the body by this method will show how greatly the sensibility varies in different regions. To do this one electrode is applied to the patient, and one to the operator, the circuit will then be closed when the operator places his finger on the patient. The operator then feels the current which is passing to the patient, and can judge from his own sensations of the degree of sensibility possessed by the patient.

145. **Nerves of special senses.**—*The auditory nerve.*—Of the nerves of special sense there is one which we may discuss at present, namely the auditory, because of the electrical treatment of *tinnitus aurium*. We have already pointed out that in health it is possible to obtain reactions when a battery current passes through the auditory nerve, and that like the motor nerves, the auditory responds more readily to kathodal than to anodal stimulation, and generally exhibits the same electrical reactions, the response being the production of a subjective sensation of sound; but in certain cases the auditory nerve answers to electrical currents more readily than it does in health. In these cases it is

supposed that there is a state of hyperæsthesia or of irritation in the nerve, and that the tinnitus is really the expression of that irritable state. In the simplest form of hyperæsthesia the kathodal closure gives sounds which persist so long as the current is flowing but cease with the opening of the circuit, while the anode (anodal closure) diminishes or abolishes the sound, which does not return during the passage of the current, and often not for hours after the current has been stopped, provided that the stoppage be gradual. So too in cases of severe deafness the reactions of the auditory nerve may be tested to determine its condition.

FIG. 69.—Aural electrode.

The auditory nerve can best be tested or stimulated by a bifurcated or divided electrode, which can be applied to both ears at once. At a pinch a binaural stethoscope answers very well, small pads of moistened cotton being substituted for the ivory ear pieces; these ends may be introduced into the meatus, or, better, may be applied just in front of the tragus and kept in place without unnecessary force by an elastic band or spring.* If a stethoscope is used, the lower portion can

* Messrs. Arnold and Son have made a very convenient divided electrode for this purpose by converting the framework of a light binaural stethoscope.

be removed, and the tubes closed up by small corks, the wire from the battery is clamped to the metal, and the other electrode may be applied to the sternum or back. When only one ear is to be influenced only one of the sides of the binaural electrode is moistened.

Hyperæsthesia of the auditory nerve is frequently met with in ear disease, but it is not present in all cases of tinnitus; when tinnitus and electric hyperæsthesia co-exist the subjective noises are readily influenced and controlled by galvanism, and many cases of cure have been effected. If the tinnitus does not respond to the electrical test it is less likely to be benefited by treatment. The opposite condition to electrical hyperæsthesia, namely, electrical torpor of the auditory nerve, is also known.

CHAPTER IX.

General Therapeutics.

Effects of electricity. Choice of current. Strength of current. Choice of pole. Methods. "General faradisation." "Galvano-faradisation." Galvanisation of the cervical sympathetic. Central galvanisation. Self treatment by patients.

146. **Effects of electrical treatment.**—The electrostatic methods of treatment have been already considered in Chapter VI. We have now to consider the methods of procedure with the battery and induction coil currents and with the sinusoidal currents produced by the alternate current dynamo. In either case the treatment may be general or local. Of general methods the one most fully deserving the name is treatment by the electric bath, which will be fully dealt with in the next chapter.

In commencing the study of electro-therapeutics the first questions to arise are the following:—(1) What results are to be expected from electrical applications? (2) When should the constant current be used, and when the interrupted? (3) What is the proper strength of current and the proper duration of treatment? (4) What is to be the direction of the current and which pole is to be applied to the affected part? (5) What are the manipulations required?

The effects produced by electrical treatment may be arranged thus:—

(*a*) *Stimulating and trophic effects.*—Electricity acts as a

stimulus, not only to the contractile tissues, both directly and through their motor nerves, but also upon the sensory nerves, and through them upon the central nervous system. It also influences the vaso-motor system. The vaso-motor influences play an important part in the relief of the pain and congestion which occur in so many morbid states, as will be seen when the treatment of sciatica and of joint affections is under consideration. In any ordinary electrical application the vasomotor effects upon the vessels of the skin are readily perceived, particularly when the battery current is used.

All living tissues are stimulated to greater activity by electrical currents, particularly when the currents are variable. D'Arsonval has shown that under the action of a varying current the elimination of urea and carbon dioxide is remarkably increased, even if there be no muscular contraction set up, so that the effect is not merely secondary to any muscular contractions produced by the treatment, he also found a similar increase, though to lesser degrees with electrostatic charging, but with constant currents of unvarying flow the effect upon the respiratory exchanges was very slight.

The improvement in health shown by rickety children, and by anæmic and debilitated persons when they are treated by general electrification with alternating or interrupted currents is conspicuous; they increase in weight, they become rosy cheeked, and they eat and sleep better. Other observers have shown that currents passed along the spine can augment the muscular force of the person so treated.

These effects are to a certain extent shared by other modes of stimulation, as for instance, by massage, by treatment with hot and cold douches, followed by friction with rough towels, and so forth; but electricity has

certain advantages over these other modes of stimulation, from its greater power of setting up active muscular contractions, and from the ease with which it can be directed to any required parts, and regulated as to strength.

The effects which peripheral stimulation exerts upon the central organs play an important part in electrical treatment, and afford an explanation of the benefits which follow even in cases where the treatment has been applied to the peripheral parts only.

(*b*) *Electrotonic effects.*—These have been already considered in § 115, and the physiological effects there described have been made the basis of a method of treatment by the continuous current. With the alternating currents of the induction coil electrotonic states cannot be expected, but with constant currents the phenomena of electrotonus may be kept in mind in treatment, for they show when the exciting action of the exalted irritability of kathelectrotonus is to be brought to bear upon a part, as in paralysis; and when the calming effects of the diminished irritability of anelectrotonus are more desirable, as for the relief of pain and spasm.

(*c*) *Electrolytic effects.*—The changes produced by electrolysis are most manifest at the surfaces in contact with the electrodes. In general medical treatment these electrolytic effects are undesirable, as they tend to produce injurious chemical action upon the skin, and are therefore guarded against by interposing some moist material between the metal of the electrodes and the surface of the body. In surgery the destruction of tissue by means of electrolysis is used for the cure of nævi and other superficial growths, for the removal of superfluous hairs, and for strictures, and it will be dealt

with in a separate chapter. Usually needles attached to the poles of the battery are thrust into the substance of the part to be destroyed. In addition to the electrolytic action at the region of the poles, there is also an interpolar action, through which molecular interchanges take place in the tissues along the whole line between the poles, the exact effects of these interpolar changes cannot be clearly defined, but it may justly be considered as producing some action; and perhaps some of the trophic or "alterative" effects which follow electrical treatment are due to these molecular movements and exchanges.

(*d*) *Osmotic effects.*—These have been considered in the chapter on physiology (§ 125) which see.

147. **Choice of method.**—A very large part of the benefits derived from electrical applications can be ranged under the heading of stimulation, and generally speaking it may be said that for stimulation pure and simple the induction coil is the best; certainly it is to be preferred in paralysis of muscles if they are able to react to it, but if they present the reaction of degeneration then the constant current may have some advantages. Fashion has had much to do with determining the choice between the two modes of treatment.

Duchenne was a firm believer in the superiority of the coil treatment for all kinds of paralytic conditions, and Remak was as warm a supporter of the constant current. The former writer declared that he had met with far better results from the interrupted than from the constant current. The latter was as confident of the superiority of his method.

Whatever benefits may be produced by electrolytic or electrotonic effects must be possessed by the battery alone; stimulation, direct and reflex, vasomotor and

trophic effects can be produced by the induction coil, and as these effects form so large a part of what is desired in cases coming for electrical treatment, the induction coil is the instrument for use in the majority of cases.

The battery has been preferred to the coil for the treatment of muscles which show the reaction of degeneration. The reason given for this is that the battery current will make such muscles contract when the induction coil can no longer do so. If the visible contraction of the muscle were the measure of the good done to it by the treatment, the reason would be a valid one. I have treated large numbers of cases showing RD with the interrupted current, and have obtained very good results in that way, and I consider that it is at least as useful as the battery current for all kinds of paralysis. When the battery current is used, and the electrode is moved over the surface of any part, the effect is that of a very gradually varying strength of current applied in succession to the different parts touched by the electrode, and it differs from the induction coil current chiefly in the rate of variation.

In order to determine whether the battery current is better than the induction coil for treating cases of paralysis, a long series of comparable cases must be treated by each method, and the results examined. I have been able to do this in the electrical department at St. Bartholomew's Hospital to a considerable extent, and I am satisfied that good results can be obtained with both methods. As it is probable that the effects of the two methods do not exactly coincide, it seems reasonable to advise treatment by both; for example, to give a patient with muscles showing RD a treatment with the battery and with the induction coil, at each visit.

The sinusoidal current may be regarded as an improvement on the induction coil current, and as useful in the same conditions. Its applications are best made in a bath of water, and will be considered in the next chapter.

In conditions other than paralysis the battery current may be far superior to the coil. Coil currents may be too sharply stimulating, they may cause pain, they may not penetrate deeply enough, they may be unsuitable for influencing unstriped muscle, if vaso-motor effects are desired, or when the intestinal or bladder muscle is to be treated. For the relief of pain the battery current is the best. Some pains may be relieved by the induction coil current applied as a counter irritant, but as a rule painful conditions and especially the pains of neuritis and neuralgia are unfavourably influenced by coil currents. With the battery current the degree of stimulation can be varied by varying the rate of change of current. A steady flow with the electrodes held still (stabile application) is the least stimulating to nerves and striped muscle; if the active electrode is slowly moved over the part (labile application) stimulation is rather greater, and it is much greater with sudden makes and breaks of current, while finally the most profound stimulation is from reversals when the current is fully on. Considerations like these determine the choice of cells or coil, and in the different paragraphs which consider detailed diseases and their electrical treatment further precise indications will be found.

148. **Strength of current.**—In determining the strength of current, it is necessary to remember that but little good is likely to follow torture, and that no needless pain should be inflicted upon the patient. With the coil the operator must gauge the strength

of his current upon himself first, and must repeat the test with every increase in its strength; a strict adherence to this rule is the best plan by far of ensuring the proper amount of caution. Patients as a rule are extremely intolerant of painful shocks, and it must be remembered that the very name of electricity is enough to make many patients at least a little anxious or alarmed on their first trial of the remedy. It is therefore wise always to exercise carefulness in the management of the instruments, in order not to appear to the patient to be reckless in handling them.

With battery currents the galvanometer provides the means of regulating the dosage. For most forms of local treatment five milliampères is sufficient, and may be too much for children or sensitive or nervous people at the commencement of a course of treatment; and the current must not be switched on or off abruptly, but gradually, the patient being carefully watched for any signs of pain or discomfort. The current collector (§ 80) must be properly made and should be tested from time to time to see that it allows of alterations in the number of cells without any breaks of circuit; when the applications are made to any part of the head or neck, additional care must be exercised, the effect upon the brain being very peculiar and unpleasant, especially at make and break. When large currents are required in the electrolysis of nævi or tumours, an anæsthetic must be used. In Apostoli's treatment no anæsthetic is used, although the current may exceed 100 milliampères. Toleration of so large a current is rendered possible by the use of a very large electrode for the cutaneous surface to reduce the density of the current per unit of area, and by the insensitiveness of the uterus to which the other pole is applied.

Generally speaking, large currents are used when deep seated parts are to be treated, and the electrodes must be large in proportion to avoid pain and injury to the skin.

The duration of each sitting may be on an average ten or fifteen minutes, but here again the patient's feelings must be taken into account, and the time shortened or lengthened as may seem advisible in each particular case.

The number of sittings varies very much, usually a considerable number are required. It is best to tell the patient at the commencement that he must not expect a magical and sudden cure, but rather a gradual slow improvement. In some cases of infantile paralysis it may be necessary to continue treatment for several years. As a general rule it may be said that at least a month of treatment, with two or three sittings a week, is required to produce permanent benefit, but of course there are exceptions, and it is not possible to lay down any precise rules. It is usual for improvement to begin early if the treatment is likely to do good. In that case the patient will be encouraged to persevere. If at the end of a month of regular treatment there is no visible change, or if the improvement has ceased to be progressive, then the treatment may be discontinued.

149. **The choice of pole.**—With the alternate currents of the secondary coil the influence of pole is reduced to a minimum, and the two electrodes may be considered to be of equal, or nearly equal value; with continuous currents there are well marked differences in the effects produced at the two poles. From electrolysis the region of the anode or positive pole becomes acid, and that of the negative alkaline in reaction, and there is a tendency to produce injury to

the skin from the chemical products of the electrolysis, if the currents be large or if the electrodes are left long in one position.

The sedative effect of the anode would seem to determine its use in painful states, while the stimulating effect of the kathode and the greater ease with which it causes muscular contraction have determine the use of the negative pole in the treatment of paralysis. It is not possible to generalise further about the choice of pole, but instructions will be found in the chapters on treatment.

The rule laid down by Remak for the direction of the flow of current was that the current should pass along the nerve fibres in the direction in which they conduct, namely, downwards to the periphery for treatment of motor affections, and upwards from the periphery for sensory affections.

Brenner preferred to consider the direction of the current as of less importance than the influence of the poles; and we should therefore speak of the choice of pole rather than the choice of the direction of the current, because the current does not run in straight lines from anode to kathode; however, the distinction between direction of flow and choice of pole is after all a subtle one. To apply the kathode to the paralysed thumb muscles, the anode being at the nape of the neck, may reasonably be spoken of either as treatment by a descending current or as treatment by the negative pole. Those who object to speak of the influence of direction of current base their objections on the fact represented in fig. 65, that round a pole applied to any part of the surface of the body the flow of current is not in one but in every direction, and therefore there can be no definite direction of the flow in the muscle under treatment, the

effects being effects of pole and not effects of direction of current. However, with the indifferent electrode central, and the active one peripheral, it is permissible to speak of treatment with descending currents when the active electrode is the kathode, and of ascending currents when it is the anode; the words ascending and descending having reference to the general direction from anode to kathode, and not implying any theory of the physiological or therapeutical importance of the direction of the flow at the seat of disease.

150. **Methods.**—Most electrical treatment is now carried out by using a single active electrode, and an indifferent electrode. The active electrode may be three, four, or five, or more centimetres in diameter according to the extent of surface to be included in the treatment, and the magnitude of the current used; the electrodes must be well moistened with warm water, the indifferent one in its sheath is then pushed down the back of the neck for patients who are dressed and sitting up, or it is placed under the hips for patients lying down. The part to be treated is then bathed with warm water, and the active electrode applied, and the current slowly raised to a proper strength; with the battery current three, five, or ten milliampères or more if necessary. The active electrode is then moved slowly over the whole of the affected part (*labile* method) or it is kept still in one place (*stabile* method), or the circuit may be closed and opened for the sake of producing muscular contractions, or may be even reversed by means of a commutator, for the same purpose. These reversals are especially powerful in exciting muscular contraction.

It is sometimes useful to have the indifferent electrode also in the neighbourhood of the part under treat-

ment; by doing this the current can be concentrated through the part tested.

In testing or treating the muscles of the hand for instance, it is often convenient to lay the indifferent electrode under the palm while the dorsum is being treated and *vice versâ*.

Sometimes too a bowl of water is useful as a medium between the electrode and the patient, who may dip a hand into the water in which one electrode is placed, and have the other electrode at the nape of the neck, or he may have two such bowls of water and put one extremity in each, when the current is to traverse two limbs at once. Treatment with the limb immersed in a bath in which the electrodes are suspended will be considered in the next chapter under the heading of the arm-bath.

When sensory impressions are chiefly desired, the skin is treated dry with a metallic brush of very fine wires; a long secondary coil of many turns is most suitable for use with this.

The induction current is to be employed where tonic or stimulating effects are chiefly desired, and with this object it is valuable in the treatment of paralysis and anæsthesia. Where the involuntary muscle requires to be roused, the battery current with interruptions and reversals is probably more effectual; thus the abdomen and the rectum may be treated for constipation, and the bladder or the uterus for atonic conditions.

Reference to the chapter on diagnosis explains the methods for testing the individual muscles and nerve trunks; their treatment consists usually in moving the wet surface of the electrode slowly over the moistened skin covering the muscles with a sliding and a rolling movement. This sliding movement is a guide to the

proper degree of moisture necessary. If either the skin or the surface of the electrode be too dry the latter will not slip smoothly, but will seem to stick, or move harshly. When this is felt the electrode must be moistened afresh. A little soap rubbed on the electrode makes it glide well.

It must not be assumed that the degree of benefit from treatment can be measured by the amount of visible contraction of the muscles, for in addition to the exercise so produced there are vaso-motor effects, and reflex effects through the centres in the cord, both of which take part in bringing about the final results.

The duration of each application should be about ten minutes, and this time must be distributed over the muscles or other parts needing treatment. When the dry brush and painful currents are employed, five minutes will usually be quite long enough, and the patient must on no account be reduced to a state of exhaustion from over-treatment. The operator should always try the current by experiment on his own muscles, in order to know exactly what amount of discomfort or pain his patient is called upon to bear.

151. **"General faradisation."**—We can now consider the methods of general treatment. The old plan of treating patients by means of metallic electrodes placed in the two hands may be regarded as a rude attempt at general electrification. Drs. Beard and Rockwell have elaborated a method of "general faradisation," the advantages of which they claim to have been the first to bring before the notice of the medical profession.

The object aimed at is "to bring every portion of the body in turn under the influence of the treatment so far as is possible by external applications."

They consider that this is best accomplished by placing one pole of the induction coil under the feet or gluteal region while the other is moved over the general body surface. The patient should stand or sit upon the surface of a large metal electrode covered with moist flannel, this must be kept warm by means of a hot water bottle or some other contrivance, as the treatment lasts for from ten to twenty minutes. The other, active, electrode is then to be moved over the various parts of the body, two or three minutes being given to the head, neck, back, abdomen, arms, and legs, in order.

The application to the limbs is less important, and may be omitted in certain cases.

The details which follow are given for reference in cases where the electric bath cannot be used. Where an electric bath exists general faradisation of this kind will not be needed.

The active electrode should consist of a metal disc or ball covered over by a large sponge of six inches in diameter, and kept moist with hot water. The object of using electrodes of large size is that by their means the current is rendered less painful, and consequently the patient can bear stronger applications; the use of the operator's hand as the active electrode* is also recommended by Dr. Beard as its tactile sensibility makes it easy for the operator to gauge both the amount of pressure he is employing, and also the force of the current used. When the hand is to be used as the active electrode the operator should put himself in the circuit by holding the wet sponge in his other hand, the current then passes through his own body from hand to

* This mode of application is spoken of as the "electric hand," or the "hand electrode." It was employed by Duchenne.

hand and so to the patient. He can vary the force of the current by altering the degree of pressure with which he holds the sponge, for when it is firmly grasped the current passes more readily and is increased, and when the grasp is relaxed the current is diminished; no bad results follow to the operator, on the contrary he shares with his patient the benefits of the treatment, and considerable development of the muscles of the arms is said to follow.

The patient may be seated while the upper part of the body is under treatment, but should stand up if possible for the application to the hips and thighs. A loose garment like a shirt or night-gown can be worn, or a large shawl or blanket may be thrown round the patient. The electrode can then easily be manipulated and moved over the surface of the body without exposure.

In the region of the head the forehead and the vertex are the most important; if the hair is at all long or thick it may be moistened, to diminish its resistance. The treatment of the back of the neck and the whole region of the spine is considered to be extremely important and should be thoroughly carried out, the electrode being slowly moved up and down along the whole length of the back.

The sensations felt by the patient should be of an agreeable nature, a pleasant thrill, without any sort of pain or discomfort. The operator must bear in mind that the sensibility of the surface varies in different parts of the body and he must adapt the force of the current to suit such variations, using the hand by preference for treating those parts which are most sensitive.

The results of the treatment are mainly tonic in their

nature, a feeling of vigour follows, depression or fatigue are relieved, the appetite is increased, the patient sleeps more soundly, there is an increase in the firmness of the muscles, and an improvement in the circulation. In some patients these results follow promptly, in others their development is more gradual; the same variability in the response of patients to other forms of electrical treatment has been observed by others.

The treatment should be carried out two or three times a week, or every other day. Currents sufficiently strong to cause muscular contraction should be employed, as soon as the patient has become accustomed to the treatment and is able to bear them without apprehension.

The process just described is doubtless useful, but there is a decided risk of the patient being chilled. The electric bath produces the same results with more comfort to the patient and should entirely supersede the above described process whenever it can be arranged.

152. **Galvano-faradisation.**—Dr. de Watteville has recommended the simultaneous use of the continuous and the interrupted currents under the above name. The method consists in "uniting the secondary induction coil and the galvanic battery in one circuit by connecting with a wire the negative pole of the one with the positive of the other, attaching the electrodes to the two extreme poles and sending both currents together through the body," we are told that "the effects of the faradic current are greatly enhanced by a simultaneous galvanization, because the points upon which the stimulus falls are in a state of exalted excitability or kathelectrotonus. Owing to the 'refreshing properties' of the galvanic current upon muscle, the fatigue and exhaustion which might otherwise be the consequence of

energetic faradisation are avoided." Dr. De Watteville has a very high opinion of the advantage of this mode of treatment, particularly for electrisation of the abdominal viscera, and in rheumatic conditions, and in atrophic paralysis. The method is still occasionally used.

The strength of each component may be about the same as when either is being used alone.

153. **Central galvanisation.**—This is a plan of applying electrical currents to the nerve centres, also introduced by Drs. Beard and Rockwell. It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head (chiefly the vertex and forehead), to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and other complaints. The duration of the treatment may be about ten minutes, and the position of the negative pole should be changed a little from time to time, to prevent any electrolytic effects upon the surface of the skin beneath it. The strength of the current should be varied between five and ten milliampéres, according to the part under treatment, and may be reduced to two or three milliampéres for the applications to the skull if the patient appear to be very susceptible.

Among recent writers upon central galvanisation Dr. Armstrong* of Buxton may be mentioned. In his paper he advises currents of one to five milliampères for the head and up to twenty milliampères for the spine, with sittings of ten to thirty minutes repeated three or four times a week, or daily. He quotes cases

* *Transactions of the Royal Medical Society of London*, vol. xxi.

in which he obtained good results in palpitation and irregular action of the heart, in exophthalmic goitre and in conditions of cerebral exhaustion and in neurasthenia and enumerates among the good effects obtained that the patients treated had improved appetite and digestion, spoke of feeling brighter, their bowels were more regular in action, and they slept better. He mentions that with currents of too great strength, or too abruptly made and broken, unpleasant effects may follow, especially in the applications to the brain. He does not insist upon the epigastric position of the indifferent electrode so strongly as is done by Beard and Rockwell.

Electrical applications to the nerve centres will probably be found useful in many cases of the kinds just mentioned. Patients to whom I have given treatment to the sides of the head for affections of the auditory apparatus have on several occasions volunteered the statement that they found the treatment had a good effect upon their general health, and Capriati* has recently shown by a series of careful experiments with healthy individuals that the application of currents (*stabile*) of ten to fifteen milliampères to the spine for ten minutes, produces a marked effect upon the muscular power of the individual, and one which lasts for several hours or days after the application has ceased.

It is probable that a more extended course of observations upon the influence of spinal and cerebral electrification in disease would give encouraging results particularly in functional conditions, and possibly in many neurasthenic states. The battery current must be employed, as that of the induction coil does not

* Influence de l'électricité sur la force musculaire. *Arch. d'électricité médicale*, November, 1899. See also Leduc, same Journal, May, 1899.

penetrate so well to the deeper parts of the body. The choice of pole does not appear to have any decided influence, although Rockwell expresses a preference for the positive pole as the active electrode.

154. **Galvanisation of the cervical sympathetic.**—This procedure was much recommended at one time, but it is not clearly proved that the cervical sympathetic has ever been appreciably influenced by electrical treatment. At least none of the ordinary physiological effects on the pupil or the blood vessels of the head and neck of stimulation of the sympathetic are produced. The treatment is carried out by placing one electrode below the ear and the other at the nape of the neck, and passing a weak current. All sorts of advantages have been claimed for this method, which has become an established part of the routine treatment of many morbid states of the central nervous system, so that in Erb's opinion it should be carried out "in every case where it is hoped to act on the circulation and nutrition of certain parts of the brain." Dr. Moritz Meyer's plan is to place a medium sized electrode at the angle of the jaw, with its surface directed backwards and upwards towards the vertebral column. The other pole should be larger, and applied to the opposite side of the back of the neck, on a level with the fifth, sixth, or seventh cervical vertebra. The kathode is usually placed in front, but not always; the current should be two to five milliampères, and the duration one to three minutes, the application *stabile*. In certain cases both sides may be treated successively. As this treatment must involve all the other important nervous parts of the neck and the base of the skull, as well as the cervical sympathetic, it would be better to adopt Dr. De Watteville's suggestion, and speak of

subaural galvanisation, rather than of galvanisation of the sympathetic.

155. **Self-treatment by patients.**—It is a matter of the greatest importance that all electrical treatment should be carried out by the medical man himself whenever this is possible, and if it is not possible for him to do so, then at least he should supervise the treatment as often as he can. Except in the very simplest applications of electricity, the results when patients are left to themselves with a battery, are generally unsatisfactory, and the usual consequence is to bring electrical treatment into undeserved discredit. It would be very nearly as reasonable for a patient to attempt to act as his own dentist as for him to try to cure himself by means of a battery without full medical advice and constant supervision. Only those who use batteries regularly are able to deal with the difficulties of making them work properly, and it is therefore absurd to place one in the hands of a patient who cannot even know whether it be working properly or not.

An exception may be made in favour of treatment by the induction coil when a long course is necessary for a particular case. The manipulations may then be carried out by a trained nurse provided she be given at the commencement of the case a few careful lessons in the anatomy of the part to be treated, and in the manipulations to be performed; she must be supervised at frequent intervals by the medical man in charge of the patient, who should never omit to make measurements and tests from time to time, to ascertain what progress is being made, and to prevent the case from being left in the sole charge of the nurse.

So too with the treatment of infantile paralysis by

means of a coil and bath-tub applied daily at bedtime; it is impossible for the medical practitioner to see to it during the whole period of treatment, and one person, the nurse or mother, must be carefully shown what to do for the particular case, but the periodical testing by the medical man himself must not be omitted. Other conditions treated by the arm-bath methods (see Chapter X.) may also be left to be carried out by the patient if he be properly instructed in the first place, and supervised from time to time afterwards.

Another simple electrical application which an intelligent patient can be taught to do for himself is the treatment of tinnitus and nerve-deafness (which see). The expense of electrical treatment when it has to be applied daily for long periods by a medical man may prevent the patient from giving the treatment a fair and prolonged trial, and on this account it is sometimes desirable to teach the patient what to do and to let him do it for himself. This is particularly the case in chronic conditions where a successful result from the electrical treatment cannot be predicted with certainty. The aid of electro-therapeutic methods is often invoked only when every other treatment has been tried without success, and thus it happens that many cases have already become chronic and difficult to move before they come for electrical treatment. Moreover the mode of action of electricity upon the tissues of the body is in its essence a gradual one, working as it does by a slow rebuilding or regeneration of the damaged organ or function, and requiring time and the exercise of patience and perseverance in its applications. It is among the poor and in hospital patients that one has the best opportunities of seeing the good which can be done by electrical treatment in chronic cases. In that class of

patient considerations of expense do not interfere to cut short the treatment prematurely, nor do they so readily throw up one kind of treatment in order to try something different. Thus it is a not uncommon experience of mine to have similar cases under treatment at the same time, the one at the hospital and the other as a private patient, and to see the latter grow restive and give up treatment when half through with it, while the former goes steadily on and makes a good recovery.

Nevertheless, in spite of what has just been stated, there is no doubt that the proper person to carry out electrical applications is a competent medical man, and that should be the rule wherever possible. To hand patients over to nurses and masseurs for electrical applications is to give away to outsiders a valuable means of relieving patients which should obviously be kept entirely in the hands of the medical practitioners themselves.

CHAPTER X.

The Electric Bath.

The bath. Accessory apparatus. The resistance of the bath. The mode of application. The use of the electric light mains. Hot air or vapour electric bath. Uses in chronic rheumatoid arthritis. Gout. Sciatica and lumbago. Nervous affections. Rickets. Anæmia. Raynaud's disease.

156. **Advantages of the electric bath.**—The electric bath is used in the treatment of morbid conditions which affect the whole system, because it provides a convenient and agreeable way of applying general electrification, a mode of treatment of great value whenever general stimulating, and tonic effects are required.

The publication of Duchenne's classical work *De l'électrisation localisée*, which gave so great an impetus to systematic electrical treatment, tended also to produce the impression that electricity was useful only in nervous diseases, and that local applications to the affected nerves and muscles formed the only plan of electrical treatment worth following.

General electrification, however, has a very powerful trophic influence upon the body, and is most useful in the treatment of many morbid states, such as debility, anæmia and chlorosis, rickets, rheumatism, rheumatoid arthritis, gout, sciatica and lumbago, and generally in diseases due to impaired and defective nutrition; also in general neuritis after diphtheria, influenza and other toxæmic conditions.

General electrification carried out by means of an electric bath is agreeable to the patient, and far more efficacious than the process of "general faradisation" or of "central galvanisation" referred to in the last chapter.

The advantages of using a bath of water as a means of conveying electricity to a patient are as follows:—

First, the water provides the best of conducting media because it adapts itself so completely to the surfaces of the body. Secondly, because by moistening the skin uniformly and thoroughly, it lowers its resistance and favours the comfortable passage of the current through the skin.

Thirdly, all parts of the body are brought under treatment together, and this simplifies matters both when the body as a whole is to be treated, or when, as in rheumatoid arthritis, there are a number of separate areas all requiring attention.

Fourthly, because the warm water serves to keep the patient warm and comfortable during the time of the application. We may also include the stimulating action of a hot-water bath upon the skin, for this is an additional therapeutic means that may often be of service in the cases which are being treated by electricity. For instance, lead poisoning is greatly benefited by electrical treatment, and also derives benefit from hot baths, so much so that a course of the Bath Waters was at one time a recognised treatment for cases of lead poisoning. In infantile paralysis too a hot bath given daily is a very useful therapeutic application and can be combined very advantageously with the electrical treatment.

It is unfortunate that the electric bath has been taken up of late by unscrupulous persons, and so has been in

danger of falling into discredit with medical men. From its manifest advantages it deserves a better fate.

157. **Apparatus and methods.**—The bath itself should be made of porcelain or earthenware, or it may be made of wood. The former is the best, as it is easily kept clean and is nice looking.

A bath five feet six inches in length is better than one which is six feet long.

The water in the bath should be agreeably warm, averaging 99° F., but it may be slightly warmer or cooler to suit the wishes of the patient. It is noteworthy that a difference of one or two degrees makes a great difference in the sensations of warmth felt by the patient at these temperatures. The bath should be so filled with water than when the patient lies in it the whole body and the shoulders may be covered. A bath thermometer must always be used to ascertain and regulate the temperature.

Two electrodes in the form of metal plates placed at the head and foot of the bath are required, and they should always be kept clean and bright. These metal plates are provided with binding screws to which the battery wires are attached (fig. 70). The best metal is copper. Zinc plates may also be used. It is no use having these metal sheets plated, as is sometimes done for appearance sake, for the plating quickly leaves the positive pole. The electrode placed at the head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. When it is wished to localise the current more or less in any part, a moveable paddle, two or three inches square, connected to the plate at the foot of the bath, may be used for this purpose. It may be used either to supplement the foot

plate or to replace it. The water should always be deep enough in the bath to cover the plates.

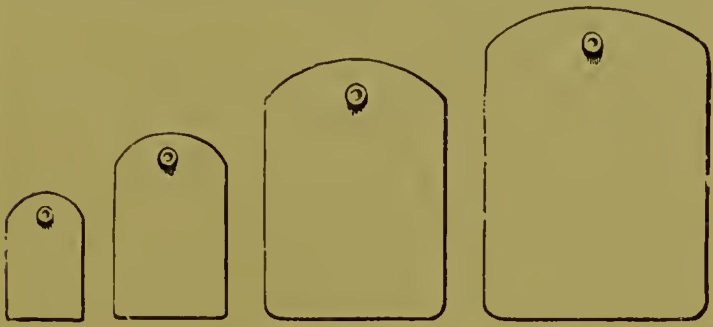


FIG. 70.—Electrodes for the bath.

The shoulders and back of the patient are kept from touching the plate at the head of the bath by a rest made of wood, something like a picture frame having

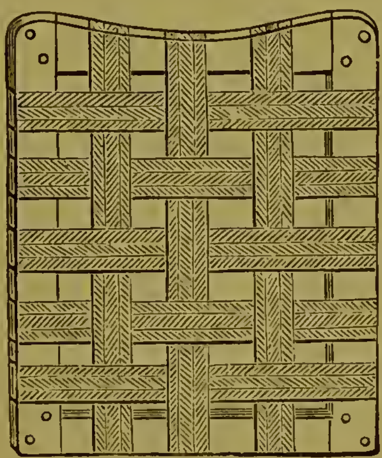


FIG. 71.—Back rest.

pieces of webbing stretching across (fig. 71). The light wicker fire screens which are made to fit on to the backs of chairs are also very convenient and comfort-

able for the purpose. Though rough to the hand when new they soon become softer and do not hurt or scratch the back ; with female patients the bathing dress gives additional protection.

The feet may be allowed to touch the electrode at their end of the bath because the epidermis on the soles is thick enough to take care of itself. If a patient prefers it, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. The arms must be extended if they are to share in the treatment, and folded if the current through them is to be kept small. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient and therefore a considerable part of the current traverses the water and is altogether lost to the patient.

The electric bath was installed at St. Bartholomew's by the late Dr. Steavenson in 1882, and was for many years the only electric bath at a London hospital. Recently, as I am informed, one or two other hospitals have recognised their advantages and have taken them into use. The bath method of applying electricity has further been extended by the introduction of arm-baths and foot-baths as well as the large general bath ; so that there are now at St. Bartholomew's Hóspital five of these small baths in regular use, to the great advantage of many patients, and with the effect of greatly simplifying the process of treatment ; better results are now obtained in many conditions of disease by bath methods than was formerly the case, when treatment was carried out by the tedious manipulations and

rubbings of the patient's limbs with small hand electrodes.

158. **The resistance of the bath.**—The resistance in an electric bath will vary with its length, with the depth to which it is filled, and with the temperature of the water.

Dr. Hedley* has contributed largely to our knowledge of the physics of the electric bath, and his book should be studied by all those who are interested in the subject. He has given the following figures as determined for a particular bath, six feet long, made of oak :—

				Resistance.
Height of water,	15 inches	with body	...	162 ohms.
,, ,,	12 ,,	,,	...	205 ,,
,, ,,	10 ,,	without body	...	245 ,,
,, ,,	7 ,,	,,	...	357 ,,
,, ,,	5 ,,	,,	...	510 ,,

Resistance of bath with water at different temperatures :—

Temperature.			Resistance.
98 Fahr.	...	...	165 ohms.
92 ,,	...	...	194 ,,
87 ,,	...	...	264 ,,

In a second edition Dr. Hedley has worked out this question afresh, using a smaller bath and measuring the resistance under conditions more closely approximating to those which obtain in actual practice. He finds that in these circumstances the resistances may be considerably less than those quoted above.

Another question of interest with the electric bath is the following :—How much of the total current passes

* "Hydro-Electric Methods in Medicine." London, H. K. Lewis, 1892. Second edition, 1896.

through the patient, and how much is conveyed by the water? The answer will depend upon the temperature of the water, and upon the volume of water in the bath; the problem is best attacked by regarding the condition as one of a divided or branched circuit; the water being one and the patient the other of two conductors; the proportion of current traversing each will depend upon their relative resistances. Moreover the thicker parts (trunk) of the patient will convey more than the average, and the thinner parts (limbs) less, so that one cannot say that the patient carries such and such a fraction of the total. Dr. Hedley,* who has made a special study of the problem, suggests that under usual working conditions it will be safe to say that the average current passing through the immersed body is about twenty-five per cent. of the total current running through the bath, that the maximum, through the trunk, is probably nearer fifty per cent. whilst at the ankles, a part of the body where the sectional area is very much less than that of the trunk, the current may be about four per cent. of the total.

M. Meylan† has contributed some experimental data upon this question. He measured the resistance of a bath first with a patient immersed; secondly with the patient removed, the water as before; and thirdly with the patient removed, but with water added to bring the level up to that which it had when the patient was in it.

The measurements were as follows:—

A. Water and patient ...	... 136	ohms	resistance.
B. Water only	... 156	,,	,,
C. Water, with water added	... 138	,,	,,

* "Therapeutic Electricity," J. A. Churchill, London, 1899.

† *Revue internationale d'électricité*, Nov., 1894.

By calculating out these figures we arrive at 1060 ohms as the patient's resistance, and 736 ohms as that of the equivalent bulk of water added in experiment C. The resistance of the patient compared to that of his own volume of water spread out in a layer over the area of the bath was roughly as 4 is to 3. The cubic measurement of an average sized man is three cubic feet or about eighteen and a half gallons.

If we compare the resistance of the water only, 156 ohms, with that of the patient, 1060 ohms, we find that under the conditions of the particular bath, the patient's body was carrying about one-eighth of the current.

As the current which traverses the water does not affect the patient and therefore may be considered as wasted, it follows that for economy of current the amount of water used in the bath should be no more than enough to cover the patient comfortably. On the other hand a large volume of water retains its heat better for the time required for the bath.

If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore useless and objectionable to make such additions to the water. In spite of this fact, some writers have advised it to be done.

159. **Choice of current.**—The direct current, the interrupted current of the induction coil or the sinusoidal current of an alternate current dynamo may be used in the bath. "Galvano-faradisation" (§ 152) has also been recommended.

Of these the first is specially indicated for the treatment of painful conditions where the coil current or the sinusoidal current is not well borne. Thus the "galvanic bath" is useful in the earlier stages of alcoholic

neuritis, in neuralgias and in acute sciatica. Again, where an effect on joints or other deep-seated parts is hoped for, as in rheumatoid arthritis, gout and rheumatism, the galvanic bath may be preferred. It has also been recommended in degenerative states of the spinal cord where irritative symptoms are present, as for instance in chronic myelitis, progressive muscular atrophy, in lateral sclerosis, and in tabes. A few cases have been published where these conditions have seemed to be benefited in this way. The vast majority, however, have received no benefit, and it is still quite uncertain whether anything can be hoped for in the future from the electrical treatment of these progressive spinal cord diseases. Hitherto, it must be confessed, we have not discovered how to apply it for their cure, so that one is almost tempted to believe that the few cases which have been recorded as successful may have been misinterpreted.

It must be borne in mind that the bath plays a quite secondary part in electrical applications, and that it is valuable rather as a convenient mode of bringing the current to the patient than as having special therapeutic qualities of prime value, so if in the future an electrical method of influencing these degenerative spinal diseases should be discovered it would then be time enough to consider whether the applications could be advantageously carried out in a bath or not. The line along which there is most promise of future possible success, is with the direct battery current applied to the region of the spine, and for this the use of the bath does not seem specially indicated, because the spine can be easily reached and treated without it.

The induction coil bath and the sinusoidal current bath are indicated where simple nutritive effects are

required. Debility of all kinds, chlorosis and other forms of simple anæmia, peripheral paralyses and infantile paralysis (except where recent or acute), the later stages of transverse myelitis, neuralgia, lumbago and sciatica, except when acute, and rheumatism and rheumatoid arthritis are all greatly relieved by the electric bath with coil or sinusoidal current. The physiological effects of both forms are similar; the differences between them are chiefly in the greater smoothness of the latter and the larger currents which can be borne with it. It is a less sharp stimulus to nerves and muscles. In all cases except one the sinusoidal current of a dynamo is to be preferred if it can be obtained, but in its absence the current of the coil may be used in its place.

For stimulating the muscles of the trunk, and especially the abdominal muscles, the sharp pulses of the induction coil are the best; thus the coil is to be preferred when one is asked to give electric baths to a patient with constipation, or with flaccid abdominal walls and pendulous belly, or in ascites. In this latter condition electrical treatment often gives good results, as will be instanced later.

In many skin diseases electric baths act very efficiently, and the use of water as the electrode is especially happy in such conditions in which the rubbing of the sore surface with leather-covered electrodes is quite unsuitable.

An interesting point which has been often observed both with direct and with sinusoidal baths, is that acne of the back disappears during a course of bath treatment.

160. **Direct current from the mains.**—The electric lighting mains (direct current) may be used for the

electric bath. The current may either be used to charge accumulator cells which are then completely detached from the charging circuit and used for the bath, or the current of the mains may be connected directly with the bath itself.

A practical point of great importance in such proceedings is the great leakage to earth from the conductors of the continuous current supply systems. The complete insulation of a bath which is even indirectly in relation with water supply-pipes and waste-pipe is almost impossible.

It is troublesome, and is very likely to fail at an inopportune moment. On a circuit of 100 volts this is bad enough, but with 200 volts or more between one conductor and earth it would be very serious. The tendency towards 200 volts systems of supply and the use of the three wire and five wire systems increase the difficulty of dealing with the leakage to earth.

In my opinion no method which depends for its safety upon the maintenance of the insulation from earth of a bath containing water is good enough to risk, and it is therefore best not to attempt to insulate the bath, but on the contrary to have it thoroughly well earthed. Its metallic water-pipe connections generally suffice, but to make sure the cold-water pipe can be joined by a soldered-on wire to the waste-pipe. The bath may then be given, the leakage to earth being allowed for and the voltage regulated by resistances in series with the bath, and fixed at both ends of the bath because the patient would in no wise be protected from discharges to earth of serious magnitude by a resistance placed on only one of the two conductors of the bath. Or the method of a shunt circuit to provide a slope of potential which can be tapped as desired (§ 68) may be used,

provided that the safety lamp (B, fig. 22) be chosen of a proper resistance.

In all electric bath treatment the utmost care must be taken with the conducting circuits and the regulating apparatus. The least neglect of the connections, both at binding screws and especially at the sliding connections which have to do with regulating and varying the strength of the current, is likely to lead to annoyance and the loss of patients. The patient in the water is so completely helpless that he may justly be alarmed at the occurrence of anything unexpected in the flow of current, and he may consider it to be dangerous to come for any more treatment if he has once received a disagreeable shock. A loose wire end in a binding-screw or a conductor broken inside its coverings of insulation may be enough to give trouble in this way. Servants can never be trusted to see to connections properly. They do not know enough, and think nothing of screwing up the end of a wire, insulation and all, in a binding-screw. For myself I follow a rule of always making trial of the entire bath circuit at the last moment before the patient steps into the water. It is never safe to omit this precaution, and it is useless to think of it when the patient is already in the bath.

161. **The sinusoidal current.**—This is the form of bath which has been most studied and used in recent years. Its employment has been made easy in many places by the systems of alternate current electric light supply which are now fairly common. For general purposes it is the best kind of electric bath to give. At St. Bartholomew's it has been very largely made use of for several years, and has entirely replaced the induction coil bath, and partially the direct current bath.

In the absence of alternating current mains a small dynamo can be used to generate the current, and may be driven by a water motor, or by a continuous current motor worked by a battery of accumulators or by the direct current mains if they are available. The instruments figured in § 71 p. 101 are well suited for this latter. There may be leakage to earth, and so to the bath, of the direct current driving the machine. To guard against this and at the same time to regulate the strength a small adjustable transformer (§ 70) is the best instrument, and the same form of appliance is wanted with the alternating electric light mains. A proper voltage for the sinusoidal bath is between four and eight volts, with an average of six.

A sledge induction coil may be used as a regulating transformer if the screw of the contact breaker be screwed down tightly so that it cannot vibrate. It must be made quite tight, or better it may be removed and the connections made directly to the ends of the primary. The secondary coil can then be used as the source of the current for the bath. The only precaution necessary is to avoid overheating the coil by applying too great a voltage to the primary. Off the 100 volt mains a lamp of eight candle-power must be arranged in series with the primary (see fig. 25).

162. **The mode of administration.**—The battery current for a bath must be very gradually raised until the galvanometer registers 100, 150 or 200 milliampères, but it is best for the first few baths to use a current not exceeding 100 milliampères. A battery of large Leclanché cells answers very well; thirty of these or twenty accumulator cells may be connected with a switch board having a double or single collector (§ 80) and a commutator (§ 81); a galvanometer graduated to

read up to 250 milliampères must be included in the circuit.

The induction coil bath.—For a coil bath a coil with a secondary of few turns is best, because the magnitude of current is relatively large, and the volts needed are small (p. 111). In those coils which are tapped in such a way that either a part or the whole of the total turns can be used, it is generally better to use the part than the whole coil. Regulation can best be carried out with a coil of sledge pattern (fig. 32). The paddle electrode, § 157, may be used. If it is brought near to the abdomen brisk contractions can be set up in the abdominal muscles.

The patient after entering the bath should be allowed a minute or so to recover from the reaction produced by the warm water before the current is turned on. The current should be increased slowly and cautiously, and the galvanometer watched, and at the termination of the bath the current must be reduced as slowly. The direction of flow should generally be from the head to the feet, the anode being at the upper end of the bath, and the kathode at its foot. There is no certain knowledge of the effect of the direction of flow in treatment by the constant current bath, but the direction here given represents the views of the late Dr. Steavenson, for the treatment of electric bath cases. A medical man should always be present to regulate, increase, or diminish the strength of the current. The patient can wear an ordinary bathing costume. With female patients the presence of a nurse or a maid is necessary, but the medical man should also remain in the bath-room while the current is flowing. As the current is slowly augmented the first sensation experienced by the patient is usually a slight pricking or tingling at the

ankles or at the knees. A metallic taste may be perceived as the current becomes stronger. Should the patient's head feel full or throbbing during the administration of the bath a cold wet towel may be placed on the top of the head. And if any faintness is caused, the current must be reduced. An electric bath must not be taken too soon after a full meal. After the bath the skin of the back near to the upper electrode will be found of a bright red hue, this will gradually pass off in an hour or two. After dressing, the patient should rest for ten or fifteen minutes before going out into the open air, and should walk home if able to do so. After an electric bath the patient generally feels exhilarated and better. Should there be any sign of languor or depression after a bath, currents of small magnitude should be employed.

It is usual for patients to feel a little inclined to sleep some hours after a bath, and it is as well to tell them of this beforehand or they may take it as an unfavourable sign.

After the bath it is best that the patient shall dress slowly in order to allow the activity of the circulation in the skin to diminish during the process of dressing. If this is not done there is a risk that the skin will perspire sensibly and that the patient will feel damp and uncomfortable, and will run the risk of taking a chill. With due care there is very little danger of cold after an electric bath. Among the very numerous patients who come to the hospital for electric baths throughout the year the taking of a cold afterwards is practically unknown.

The duration of the bath should be for ten or fifteen minutes, and they may be given on alternate days. Twelve or fourteen baths are needed to produce a good

result in most cases, and may be taken to constitute "a course." But in many chronic states more than this number will be wanted.

163. **Combined electric and hot air or vapour bath.**—Electricity has been applied to patients when in a hot air or vapour bath. This form of application is said to possess certain therapeutical advantages. Patients who suffer from depression or are unable to bear the water electric bath may be able to take the hot air or vapour electric bath. The bath is given in a cabinet constructed for the purpose. The patient is seated or stands upon a surface connected to one pole. The other pole of the battery can be connected with special electrodes to be applied to different parts of the body. The cabinet contains a hot water coil.

During the bath the operator applies the electrodes to that part of the patient's body which is to be treated. Sometimes a projecting metal arm is used with the end covered by sponge against which the patient's back or epigastrium can rest. This projecting arm is fixed to the back or side of the cabinet and connected with one of the poles of the battery.

A hot air or vapour electric bath is nothing more than the application of electricity to a patient whose skin is rendered a better conductor through the warmth and perspiration that is induced. The skin is softened and so rendered a better conductor. The vapour bath is considered more relaxing and soothing than the hot air bath. Although the current is not conveyed by vapour or steam, it may be carried by an unbroken jet of water; and douches can be contrived which will at the same time electrify a patient, if he stand or sit upon a conductor so as to complete the circuit.

164. **The electric douche bath.**—In the *Revue internationale d'électrothérapie* for June, 1894, there is an interesting account by Dr. Guyenot, of Aix les Bains, of his method of applying electricity by means of douches. The current is led to and from the patient by two streams of water, the conductors being connected to the metal nozzles through which the water flows, and he insists upon the ease with which the jets of water can be made to carry the current to the whole surface of the body or to any part of it so as to give the effect of a general or of a localised electrification. Careful working details of the modes of applying the battery current or the induction coil current either local or generally, will be found in his paper, which is well worthy of attention.

Of late years electrical applications have come into very general use in spas and health resorts, not only abroad but also in this country, and this speaks volumes for the superior advantages of electricity over hydrotherapy pure and simple. Electro-therapeutics also find a more favourable public at such places than they do in large and busy towns, for patients who cannot spare the time for a regular course of treatment when at home are able and willing to do so when staying at a health resort, and detached from their daily business.

165. **The arm-bath.**—The use of the bath method of applying electricity to the forearms and hands or to the feet is often very convenient. Any non-conducting vessel to hold water may be used if of suitable size. Oblong stoneware troughs can be had which are exactly suited to take the hands and forearms, and Mr. Miller (93 Hatton Garden, E.C.) can supply them with electrodes already fitted.

The best form of electrode is of sheet metal cut out in one piece in the shape of a tennis bat ; the handle is bent over into a hook and serves to hang the electrode from the end of the trough. It is flexible and can be bent to fit any form of trough or tub, and is fitted with a binding screw.

The arm-bath is specially suited for cases such as paralysis of the muscles of the forearms and hands, as for example in extensor paralysis from lead poisoning or from pressure, in paralysis from various injuries to the nerves of the forearm, in rheumatic and gouty affections and rheumatoid arthritis affecting the wrist and finger-joints, in stiff wrists or elbows from injury or disease of those joints, in chilblains and Raynaud's disease affecting the hands, while the foot-bath is valuable for applications to the feet in the last-mentioned disorders. A consideration of this list will show how often the arm-bath is of service, particularly in general practice or in the electrical department of a hospital. Moreover the arm-bath greatly simplifies the process of applying electricity to a patient, by doing away with the tedious business of rubbing the electrodes over the affected parts. For these reasons the arm-bath is a most valuable method of applying electricity and one which in my opinion deserves very general adoption by the profession. The constant current, the coil current, or the sinusoidal current may be applied in the arm-bath with equal advantage. The last-named is the most generally useful, except for joint affections.

When a bath of any kind is so arranged that one electrode only is immersed while the other is directly attached to a portion of the patient which is not immersed, it has been called a monopolar bath as dis-

tinguished from the ordinary or di-polar bath. A monopolar bath is not often necessary, it is mentioned here because it will be incidentally referred to later in this chapter. For a constant current arm-bath from 9 to 12 cells may be used. In a trough-shaped vessel this will give a total current through the bath of from 25 to 40 milliampères.

166. **Chronic rheumatoid arthritis.**—An affection for which the electric bath is most useful is chronic rheumatoid arthritis. Electric baths are valuable in all stages of the disease, and though they will not cure inveterate cases, they will do very much to arrest the progress of the disease, to reduce the pain and swelling

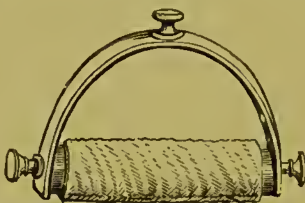


FIG. 72.—Handle for rheumatoid arthritis.

of the joints, and otherwise to produce great amelioration in the symptoms. When the hands are chiefly affected a pair of metal handles of suitable sizes (fig. 72) covered with flannel may be employed to concentrate the current upon these parts.

The handles are attached by conductors to that pole of the battery which is connected to the foot plate. The current is thus concentrated upon the arms and hands. But this local application of the current to the affected parts does not represent the whole purpose of the bath, nor is an arm-bath so good a method of treatment in this disease as is the general bath, which exerts an influence on the whole system.

The hands may also be made to grasp a metal bar supported across the bath and covered with moistened flannel, the monopolar bath. In this position the hands are raised out of the water and carry the whole current, which must be adjusted to suit the altered conditions. When concentrated in this manner on the hands the patient cannot bear more than ten or fifteen milliampères. When changes in the direction of the current are to be made, the current must first be reduced to zero and then increased again. If the current were broken or reversed suddenly, the patient would receive a very unpleasant shock. This method is not so good as the general bath with concentration on the affected parts by the handles figured above. When the forearms and hands alone are affected the arm-bath daily may be used alone if no full length bath can be obtained.

After the completion of a course of baths it is possible to notice some improvement in the condition even of advanced cases. A patient for instance who could only climb upstairs slowly and painfully becomes able to make the ascent without assistance; or a woman who could not hold her needle or perform her household work finds that she is able to do so fairly well.

When the larger joints, such as the knees, hips, or shoulders, are the seat of rheumatoid arthritis, the current can be localised by the use of the small metal paddle (§ 157) placed in some position in the bath so as to concentrate the current upon the affected joints.

Dr. Chauvet* in a paper on the treatment of chronic rheumatism at Royat has recommended the arm-bath with lithium carbonate and reports fifteen cases treated in this way with currents of twenty or twenty-five milliampères. He obtained good results in more than

* *Arch. d'électricite médicale*, April, 1898.

two-thirds of the cases; most of the remainder discontinued the treatment after a small number of baths and did not show any result. In the course of his paper he discusses the symptom known as Heberden's nodes, and is not able to say that he ever saw these disappear as a result of treatment. It is worthy of note that I have seen this year a patient in whom one of Heberden's nodes has disappeared and others have softened, with great general improvement of the symptoms, during a course of induction coil arm-baths continued for six months.

Gonorrhœal rheumatism has also been treated by electric baths on the same plan as that followed in the treatment of rheumatoid arthritis, but not with quite such satisfactory results.

167. **Gout.**—The electric bath is an excellent means of treating this disease, both for local applications to gouty joints and for combating the general gouty state. For the former the local arm-bath with the battery current is the best; for the latter the general bath with the sinusoidal current is to be preferred. Good results have been reported by many observers with the arm-bath, and particularly when a solution of chloride of lithium has been used instead of plain water (see § 125). Guilloz* has reported two cases of severe and old-established gout which were successfully treated by local monopolar electric baths with lithium carbonate. He recommends large currents up to 200 milliampères, the positive pole in the bath with the affected limb or limbs and the negative pole, of large size, applied to the back; time of the applications from twenty to thirty minutes. The patients were also treated by auto-conduction (§ 110) and high frequency currents. The

* *Arch. d'électricité médicale*, June, 1899.

first patient was twice treated for two severe attacks, each time with rapid good effect. The second patient also did well in spite of the fact that Dr. Guilloz says that he continued to follow a dietary which was "of the most detestable" and that his excesses in eating and drinking were renowned ("*passent a l'état légendaire*").

168. **Sciatica.**—This is an affection well suited for treatment by the electric bath. Very good results are obtained by ordinary local treatment in this condition, but it is often more convenient and more agreeable to the patient to be treated by means of the bath, and the results are quite satisfactory. Some may respond quickly to the treatment, and some slowly, but all do well.

From a very considerable number of cases of rheumatism, rheumatoid arthritis and sciatica treated by the electric bath, I am of opinion that the induction coil current, or better still, the sinusoidal current, is as often useful as the battery current; indeed, I have sometimes found that the patient remained unimproved by the latter, and then began to progress favourably when the sinusoidal current was substituted for it. In other cases, I have known a patient improve under the constant current; and, returning again a year later with the same symptoms, improve equally well under the other mode of treatment. It sometimes happens that the interrupted or alternating current increases the pain in sciatica, particularly in acute and recent cases. When this is the case the constant current acts more favourably, and may be applied directly by means of pad and electrode, or in the bath with the paddle brought near the affected region. It seems rather better to make the active electrode negative than positive in this case.

These conflicting experiences make it difficult to settle the question of the choice of current in these disorders. One might, perhaps, suppose that the improvement under the alternating current was rather due to the indirect effect of systematic general stimulation, while the constant current might act by some direct local action, but it is better, in the present state of our knowledge, to be content to note the fact that the sinusoidal bath or coil bath may be successfully used in many conditions for which the continuous current bath has been recommended, and that the chief indication for the latter is the presence of pain made worse by the alternating current.

For the last few years I have used the alternating current of the electric light mains in most of such cases both at the hospital and in private practice, and have had better and more rapid good results than when using the constant current bath. The alternating current of the mains is therefore the form of current with which I am most well acquainted.

The physiological properties of the sinusoidal current were first indicated by D'Arsonval, and their applications to medical treatment have been made the subject of an interesting series of papers by Drs. Gautier and Larat.* This gives details of apparatus and short histories of twenty-seven cases. Among the more striking cases there mentioned is one of obstinate sciatica of two years' duration, which yielded after five baths, although previously rebellious to all kinds of treatment, including the constant current, the interrupted current, and electrostatic sparks ; and another of acute sciatica, which for six weeks had compelled the patient to keep his bed. He was completely relieved by the sinusoidal current baths in a week.

* *Revue internationale d'électrothérapie*, vol. iii.

169. **Nervous affections.**—Much time has been spent over attempts to cure grave spinal cord diseases by electrical applications, but hitherto without success, and because electricity has failed in such things as tabes, progressive muscular atrophy, chronic myelitis, &c., it has been condemned by some as useless for any kind of treatment. At the same time it is very right and proper that electricity should be tried in this class of disorder, and it may be that some day a successful method of electrically influencing the nutrition of the spinal cord will be discovered. The direct treatment of the brain and cord have not been very fully worked out up to the present.

The subject is introduced here in order to enable me to put on record some of my own work in spinal cord diseases by the sinusoidal current with the bath. During the past five or six years I have received for treatment at the hospital a certain number of cases of locomotor ataxy, of progressive muscular atrophy (Aran-Duchenne, Landouzy-Déjerine, Charcot-Marie types), of chronic myelitis, syphilitic and others, and have given them courses of baths during weeks or months, or even in some cases during years. I have never been able to satisfy myself of a single complete cure in any unequivocal case, although I have frequently thought that the progress of a case was temporarily arrested by the applications; for instance patients have often returned after giving up treatment to ask for further treatment as they had lost ground after the discontinuance of the baths; this especially in myopathic atrophies. A few cases of early or doubtful tabes have appeared to have been cured. One patient sent to me as pseudo-hypertrophic paralysis, and with symptoms closely resembling that disease, did recover

completely, but the diagnosis was a little doubtful to my mind from the first. The class of cases above enumerated should therefore be considered unsuitable for treatment by general electrical stimulation.

It is quite different with cases of functional or slighter diseases of the nervous system, with infantile paralysis, and with peripheral neuritis. Among these disorders there are many cases which derive great advantage from electricity, and they will be considered at greater length in succeeding chapters.

The sequelæ left by influenza, which sometimes produces symptoms of considerable mental and nervous failure, or even a definite neuritis with reaction of degeneration, are promptly relieved by the electric bath. I have had a number of these cases, and have seen them rapidly improve; the same holds good for diphtheritic paralysis. In cases of severe alcoholic neuritis, the patients gradually regain power in the limbs and make good recoveries even after lying helpless for several months. The return of normal electrical reactions in the muscles of the legs may not take place until some time after the recovery of voluntary power, but in the end one will obtain normal electrical reactions and good development in the muscles which formerly showed wasting, paralysis, and a marked reaction of degeneration. Cases of cervical and brachial neuralgia, and neuritis in most of its forms, may be treated with great success by the electric bath or arm-bath.

170. **Metallic poisoning.**—In patients with lead poisoning, treated by means of the bath or arm-bath with sinusoidal current, the results have always been most encouraging. Recovery is the rule, but three or four months of treatment may be required in severe

cases. But among hospital patients who come in contact with lead during their work, the results are seldom very permanent, because they are apt to return to their occupation at the earliest opportunity, and so become poisoned afresh as soon as they have regained a little muscular power.

In one instance a patient with lead palsy was treated with the battery current, and the electrodes of the bath were examined to see whether any electro-deposition of the metal could be brought about in the course of the bath. A grey deposit, which gave the proper chemical reactions of lead, was found upon the negative electrode; but it was not possible to be certain that the lead had come from the patient's tissues, for it might have been derived from lead compounds upon the surface of his body.

The removal of metallic poisons from the body by electrolysis in the electric bath has not had much attention since the time of Poey, who made a communication on the subject to the French Academy of Sciences in 1855.* In this it is stated that mercury in metallic globules had been deposited upon the negative pole of the bath in which a person was placed after a course of mercurial inunctions. Here again it is most likely that the mercury, which seems to have been properly identified by chemical tests, must have come from the surface of the skin of the patient.

Althaus refers to a case of argyrism in which a large number of baths were tried with the object of removing the silver deposited in the patient's skin without the least success. Mercurial tremors are not often met with, but I have notes of one very well marked case in

* Becquerel, " Traité des applications d'électricité à la thérapeutique." Paris, 1857.

which a rapid cure followed a course of treatment by sinusoidal baths.

171. **Rickets.**—Children with rickets quickly respond to the electric bath. It is surprising to see how quickly they begin to improve in general health, and in their powers of standing and walking, and to see them gain in weight under the stimulating effect of the treatment. I have observed rapid improvement in several severe cases which were sent over to the electrical department at St. Bartholomew's, because their inability to walk had led to the belief that infantile paralysis existed. In Italy, Dr. Sagretti and Dr. Tederchi have reported a number of cases of rickets cured quickly and completely by electric bath treatment.

172. **Anæmia and chlorosis.**—The electric bath is not often resorted to for the treatment of these conditions, because good results can generally be obtained by simpler means. In obstinate cases where ferruginous and tonic treatment does not answer satisfactorily, the electric bath should be tried. By its use the metabolic processes of the patient can be so efficiently stimulated that increased appetite and vigour can be secured for the patient, with improved colour, and a marked gain in weight. Under these conditions the catamenia will be re-established in a proper manner. I have several times had these patients under treatment by electric baths when they were not doing well under iron, and have found that the results of general electrification are distinctly valuable. Both in rickets and in chlorosis we have to do with simple forms of defective nutrition in which a simple electrical stimulation suffices to bring about a cure.

173. **Mental diseases.**—The abundant evidence which we possess of the value of general electrification

in the simpler forms of nutritional failure seems to point to the importance of applying the same kind of treatment in certain forms of insanity or mental failure. As a rule cases of this kind are not often met with in general practice, nor among the out-patients of general hospitals, and it will rather be in asylum practice that opportunities for trying electrical treatment will arise. A considerable amount of evidence has already accumulated to show that something may be done in this way. A valuable summary of the position up to about 1885 will be found in Erb's work on Electro-therapeutics,* together with numerous references to the writings which should be consulted in connection with the subject. Two cases which have come under my own experience may be mentioned here. One was that of a man referred to me by Dr. Gee with a note saying that the patient showed many of the signs of progressive dementia, but that as his symptoms dated from a recent attack of influenza he might receive benefit from electricity. The patient recovered rapidly from a short course of sinusoidal bath treatment, he regained his memory which he had completely lost, and was able to go back to his work. The other patient was a shorthand writer who had broken down in health completely. He was strange in his manner and sat huddled up in a dejected attitude. His wife said he was much changed in temper, and told me that on one occasion he had been found wandering about and had been brought home by a policeman. When he came he was treated by sinusoidal baths twice a week. A gradual improvement began and all his symptoms slowly left him. After three months he was able to begin work

* Von Ziemssen's "Handbook of General Therapeutics," vol. vi. Smith, Elder & Co., 1887.

again, and has continued well for more than a year. Dr. Robert Jones of Claybury Asylum tells me that he has been using induction coil baths in the treatment of some of his patients for two years or more and finds that they are of decided value.

He has kindly sent me the following communication on the subject:—

"I have tried the electric baths in the case of adolescents mostly. In these and others the form of insanity was that of melancholia, some of the cases presenting well marked melancholia attonita (or anergic stupor).

"These cases are marked by a gradual deterioration as a rule; they stand or sit about in a fixed or passive attitude and have almost always to be considerably coaxed (if not forcibly fed) in order to get them to take nourishment. The mental condition is so unsatisfactory that some persons call the disease primary dementia and it is certainly not a very curable form.

"After my conversation with you and my encouragement by your method of bath treatment I tried it upon eighteen males and five females. The record of weight in the case of the females was not kept; of the five cases all improved greatly in health, but two were phthisical, and whilst undergoing bath treatment both gained several stones in weight. One died of phthisis, one was discharged recovered; one has developed epilepsy, and one has recovered sufficiently to lead a useful life as a helper in the asylum.

"Of the eighteen men, nine have left the asylum (six recovered, two relieved, and one improved but not recovered). All the men gained weight under treatment (they were weighed weekly and the record has been kept), the average gain of the nine who left the

asylum being seven pounds during the bath treatment, which lasts for an average period of about seven weeks, but many received baths during nine or eleven weeks. The greatest gain of one case whilst under treatment was twenty-two pounds, the next nineteen pounds. Of the nine cases remaining under treatment, one is phthisical, one is suffering from progressive muscular atrophy; the others are considerably improved mentally, the stupor or profound melancholia having quite passed off, but they have not been well enough to be discharged from the asylum. I consider the results to be satisfactory. So little has yet been done in regard to the systematic treatment of the different forms of insanity by electricity that it is perhaps premature to form definite conclusions, but I consider that in electric baths we have an excellent and valuable stimulant to metabolism. The skin in the insane is in an abnormal condition, but whether the improvement after baths is due to the bath or this with electricity I am not prepared to say.

"I should especially recommend electric baths in melancholia in adolescents and apathetic cases such as I have referred to. Certain puerperal cases of melancholia have also done well under treatment."

174. **Disorders of circulation—Raynaud's disease—chilblains.**—The electric bath is useful in cases of defective circulation, as in Raynaud's disease, chilblains, and in cases of dead white pallor of the extremities. Both the continuous and the interrupted current have been employed with good effect. One of the first signs of improvement in the numerous cases of infantile paralysis which have been under my care, is that the circulation in the paralysed parts is improved, the limb becomes warmer, and the chilblains disappear. Either

a general bath or an arm- or foot-bath can be used.

Dr. Barlow in his appendix to the translation of Raynaud's "Essays on Local Asphyxia,"* recommends the constant current monopolar arm-bath, in the following words:—"The use of the constant current as recommended by Raynaud, has been adopted with advantage by several observers in cases of local asphyxia. The method which has been found most satisfactory by the translator, in four separate cases, has been the following:—Immerse the extremity of the limb which is the subject of local asphyxia in a large basin containing salt and water; place one pole of a constant current battery on the upper part of the limb and the other in the basin, thus converting the salt and water into an electrode Employ as many elements as the patient can comfortably bear, make and break at frequent intervals so as to get repeated moderate contractions of the limb. In a typical paroxysmal case, if the two limbs are similarly affected, it will be found that the limb which is subjected to the above treatment will more rapidly recover than the one which is simply kept warm."

For chilblains the arm-bath or foot-bath with induction coil is the most convenient domestic remedy, and succeeds in all but the most severe cases. I have used this mode of treatment in a number of cases and have repeatedly seen the prompt disappearance of chilblains follow its use. Moreover patients have several times informed me that after the cure of their chilblains by a course of coil baths they have found themselves with more resisting power afterwards, so that a course of baths at the beginning of winter has been sufficient to

* New Sydenham Society, "Selected Monographs."

get them through the whole of the cold weather without any return of the chilblains afterwards. The effect of the treatment therefore is more or less lasting. In the most severe cases of chilblains the constant current bath must be used. Its effects upon the circulation seem to be more intense than those of the coil, and after a constant current bath warmth and redness of the skin is greater than it is after a coil bath.

Patients who know by experience that they are likely to have severe "broken" chilblains should not delay too long before beginning with the treatment, as the current acts very painfully upon any raw ulcerated surfaces. If these already exist they must be covered with a strip of oiled lint during the bath.

CHAPTER XI.

ELECTRICAL TREATMENT IN DISEASES OF THE BRAIN AND THE GENERAL NEUROSES.

Cerebral disease. Hemiplegia. Epilepsy. Chorea. Hysteria. Hypochondriasis and neurasthenia. Insomnia. Tremors and spasm. Writer's cramp. Tetany. Exophthalmic goitre. Migraine and headache. Mental diseases.

175.—**Cerebral disease.**—Although to a great extent it has been customary in treating cases of disease of the central nervous system to apply treatment to the peripheral parts only, nevertheless the seat of the lesion producing the paralysis or other symptom ought also to be brought under the influence of the current if it can be accomplished without risk.

Coil currents are not suitable for applications to the brain. In the first place the skin of the head is rather sensitive, and intolerant of all but very mild induction currents, and in the second it is not the simple stimulation of the brain which seems to be indicated so much as the "alterative" effects, and vaso-motor effects which may be set up by the battery current.

It has been said that induction currents do not penetrate the skull, and that this is the reason why applications of these currents do not give the usual evidence of stimulation of the motor cortex. This belief, however, is absurd, on physical grounds, and it has been proved experimentally that currents applied to the head do traverse the brain, and if continuous currents have been

proved to do so, nothing on earth could prevent alternating currents from doing so.

Owing to the rounded shape of the head the conditions favour diffusion of current, and therefore the density of current (§§ 34 and 112) is greatly lowered as soon as the parts inside the skin are reached. The induction current though felt strongly at the point of contact of the electrode, is diffused away almost to nothing by the time it has reached the brain. On this account the battery current is the most suitable for treating the brain.

The effects perceived when battery currents are caused to pass through the head, are peculiarly unpleasant at the moment of make and of break, and as a general rule sudden makes and breaks are to be avoided as much as possible in applications to the head. The patient should be warned beforehand of the sensations he will experience, and when opening or closing shocks are necessary, it is as well to give the patient a signal that he may know when to expect each. The sensation of a flash of light produced by stimulation of the optic nerves seems to be peculiarly alarming to some patients, probably because they connect it with their previous experiences of lightning flashes. Though we must not forget Duchenne's accident when treating the brain (see § 121), we may reasonably hope not to meet with a similar disaster in our own experience.

A certain amount of work has been done on the electrical treatment of affections of the brain, although in this, as in many other branches of electrical treatment, English medical men have contributed little. Much more, however, requires to be done before the modes of application and the results produced can be firmly established.

The objects to be hoped for from applications to the skull in cerebral disease are as follows:—to promote the absorption of extravasated blood, to assist the circulation through the brain, to remove congestion, and to improve nutrition. All these may be classified as vascular effects, and a certain amount of evidence, partly experimental and partly clinical, has been collected, which seems to show that definite effects can be set up within the skull by electrical applications.

Professor Leduc of Nantes (*Arch. d'électricité médicale*, May, 1899) in a lecture on Cerebral Galvanisation relates the case of an elderly Judge who had been under his care at one time for facial paralysis. He was treated with the battery current and soon recovered from his paralysis, but afterwards continued to come at intervals for more treatment because of the comfortable feeling of increased mental vigour which the galvanisation of his head and neck afforded him. His words are so striking as to deserve quotation. He said, "I feel lighter, and my ideas are more clear. I can concentrate my attention more closely upon my work, I struggle more successfully against the sleep-producing effect of long pleadings. I grasp more clearly the arguments which are advanced before me, and I can weigh them more exactly; in fact, I find my intelligence is brighter and my work is more easy to do, and for that reason I come to you for an electrical application whenever I am confronted by a fatiguing or difficult piece of work." A patient of my own, who had been receiving electrical treatment for nerve-deafness, though not very greatly improved so far as her hearing was concerned was so conscious of the good effect produced upon her general condition as to be most anxious that her husband should also be treated in the same way!

Prof. Leduc concludes his lecture with the following statements:—

1. The brain is quite accessible by the battery current.

2. Applications to the brain are free from danger, and if carefully applied are free from discomfort.

3. Negative applications appear to excite the functions of the brain, while positive seem to have a calming and depressing action.

4. There is reason to hope for good effects in many diseases of the brain.

5. Negative applications afford a means, probably the best means, of relieving the effects of mental overwork, and of raising the intellectual powers to their highest level.

176. **Hemiplegia.**—In the less severe cases of hemiplegia good results are commonly obtained by electrical stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. I have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. In hospital practice the difficulty with old hemiplegic cases is rather to know when treatment may be discontinued, for as a rule the patients seem to wish to continue attendance indefinitely. Improvement up to a certain point is the rule. After that continued treatment does very little. Much cannot be expected when there is well marked late rigidity. The series of cases recorded by Prof. Erb* seems to show that after an attack of hemiplegia the muscles may be left in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will,

* "Electro-therapeutics."

although there may be no absolute interruption in the conducting paths. Thus a patient may at once recover much of his lost power after a single vigorous electrification of his affected limbs. It is therefore very important that this treatment should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until four or five weeks after the attack, in order to avoid all danger of setting up fresh changes in the brain, and it may be repeated three or four times a week. A certain number of patients will be distinctly improved thereby. Most of the improvement likely to be obtained in this way may be expected to show itself in the course of the first month. It is also advised by Erb and others that further treatment may be directed to the seat of the lesion in the brain, the continuous current being employed, the anode to the forehead and the sides of the head, and the kathode to the nape of the neck, the former electrode being slowly moved to and fro (labile) without interruptions; this direction of the current has been chosen on account of its following the course of the motor tract. A current of one to five milliampères is recommended, and the active electrode should be of medium size. This treatment is to be carried out daily for four weeks, the duration of each sitting being not more than five minutes. If aphasia is associated with the hemiplegia the anode may be applied to the region of the third left frontal convolution and island of Reil. I have no personal experience of the results of direct treatment of the brain in hemiplegia. As the morbid process in the brain is essentially a destructive one there must be limits to the amount of recovery which is possible. These limits will be determined by the extent and the situation of the damaged part.

177.—**Epilepsy.**—This has been attacked by electrical methods, but without any practical advantage. Arthuis states that he has seen good results follow from electrostatic treatment.

Althaus gives three cases where treatment at once diminished the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits was prolonged from a few days to two months. Erb also reports that he has received a decidedly favourable impression from the treatment of epilepsy by the constant current. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute, and secondly in the middle line of the head in front with the same current and for the same length of time, the kathode being over the occiput. The treatment of the seat of the aura as well is recommended by Althaus.

178. **Chorea.**—Statical electricity has been successfully tried in this disease. In 1849 Dr. Golding Bird* reported that out of thirty-seven cases thirty had been cured by electrical treatment, while five of the others were relieved. The plan of treatment was the application of sparks to the spine. The shocks from a Leyden jar were found to be decidedly harmful.

The patient was insulated and connected with one of the conductors of the electrical machine. A ball-electrode with insulated handle was attached to the other conductor, and sparks were applied to the spinal column and the affected limb, until a papular eruption was produced. In the case of children the mother or nurse was insulated with the child in her arms, and sparks applied to the child's back and limbs as before.

* "Lectures on Electricity and Galvanism," London, 1849.

In the *Guy's Hospital Reports* in 1853, Sir William Gull reported twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repetitions, effect a favourable change, and enable us to administer other means of cure." In spite of this emphatic testimony the treatment is now-a-days quite neglected.

In the United States Monell has reported recent successful cases.

With modern machines the negative breeze to the spine would probably alarm the patient less and prove as efficacious (§ 102).

In chorea electrical treatment should surely be tried, at least in cases which have lasted a long time, and resist the ordinary medical treatment by rest and drugs.

It often happens that patients seem to recover imperfectly from chorea, because certain habitual movements remain when the disease has otherwise disappeared. For these late symptoms electrical applications are very suitable, I have seen them quickly dispelled in several such cases by a course of electrostatic treatment with sparks. Indeed all those which I have been asked to treat for this condition have recovered within two or three weeks.

Recent severe chorea has never come under my care for electrical treatment. I am therefore unable to support or deny the statements of Golding Bird and others, as quoted above. The general feeling on the matter seems to be that electrical treatment might do harm by alarming the patients suffering from it. But the breeze discharge is not painful or alarming.

The paretic states which are often left after chorea may be treated by electricity with great advantage.

179. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and from the peculiar nature of the affection, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the literature of Medical Electricity, from the time of John Wesley's "Desideratum" onwards, is full of more or less wonderful cures of such cases by electricity. At the same time the value of electrical treatment lies rather in the direction of dispelling symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties and disappointments, even in hysterical cases, although good results will often be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to my notice. Strong galvanic shocks have been used for cutting short an hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesiæ and spasms; for these symptoms the induction coil is most usually employed, either with an ordinary electrode or with the

dry metallic brush. Statical treatment, especially the treatment by sparks, is also valuable in these cases, and has been very largely practised. Hysterical aphonia can sometimes be dispelled by coil currents applied to the throat from outside, and for the most part this method is better than the more severe application of the electrode to the fauces, or to the larynx, because the patient will not always submit to the latter method. For the hysterical condition, as distinguished from the special symptoms, it is advisable to use general electrification, and especially the electric bath or statical charging and breeze treatment.

The electrical treatment of hysteria does not consist merely in severe applications; the treatment may be briskly applied, but pain must not be deliberately inflicted. In the treatment of functional aphonia by sparks or shocks, there are cases where the patient becomes alarmed and screams out aloud and so becomes cured. Others show the greatest equanimity and do not cry out, neither are they cured, or at best only after many visits.

An important consideration is the diagnosis between hysteria and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease, for instance with phthisis; moreover, when the diagnosis has been based upon the alleged presence of a persistent localised pain in a female patient, it may after all turn out to be due to some serious latent mischief. I have known two cases where patients with early malignant disease of the vertebræ were supposed to be suffering from hysteria alone.* It is not wise to diagnose all sorts of condi-

* Cf. Dr. Buzzard, *Brain*, 1890. "On the Simulation of Hysteria by Organic Disease of the Nervous System."

tions as hysterical merely because they are not understood.

180. **Hypochondriasis and neurasthenia.** — In these conditions the methods of general electrical treatment are of great value, especially the electric bath, which answers very well to the indications for treatment required by these cases. Direct treatment to head and spine with the constant current (see § 175) should also be tried. The conditions which are now-a-days described under the general term neurasthenia, are conditions of general debility or of debility affecting chiefly the nervous system. Usually they depend upon a failure of nutrition, often started by some definite disturbing cause, such as mental worry or a severe illness; the digestion becomes impaired, and this keeps up a state of defective nutrition until at last the patient falls into the more or less pitiable condition which is so well known.

In other cases errors in diet, extending over a long time, may be the cause of the neurasthenia, and the patient himself may be quite unconscious of this. Frequently these patients will declare that they are most careful in their food, but if the medical man has opportunities of observing them he will soon find out whether this is the case or not. Generally it is not so. Dyspepsia is almost universally present, and should be carefully attended to. The difficulty of curing neurasthenics by a few bottles of medicine also tends to make the medical man grow impatient; but indeed it is unreasonable on his part to expect a cure in that way. The only proper way of treating neurasthenics is by enforcing a proper diet and proper rules of life, and by insisting on adequate and refreshing exercise, assisted by some method of general stimulation, and it is in this

capacity that general electrification serves as a useful aid. Many people tend to become neurasthenic in the slighter degrees when their daily cares exceed a certain point, and when business matters or other troubles begin to spoil the appetite, and to interfere with proper exercise and a due amount of sleep, then troubles of the neurasthenic sort are likely to begin.

I have had opportunities of seeing the effect of general electrification upon a number of these cases, and I am satisfied that vigorous stimulation by the electric bath and induction coil or sinusoidal current, carried out two or three times a week, has far more effect upon neurasthenics than any other mode of treatment. Of course it should be used in conjunction with proper rules for diet and regimen, and the original depressing cause of the disease should be found, and if possible, eliminated. If this cannot be done no treatment will be of much use. For instance, where domestic unhappiness or discontent is a factor, one may treat in vain.

181. **Insomnia.**—General electrification frequently produces a tendency to sleepiness in patients. The sinusoidal or coil bath has an especially strong effect in predisposing to sleep. So has the static charge (positive) with head breeze. This application may be given for half-an-hour or longer. Armstrong has found central galvanisation very useful (§ 153).

182. **Tremors and spasm.**—The various kinds of tonic and clonic spasm, and of tremors, come not uncommonly for electrical treatment because many of them are so difficult to relieve by any other known method. The results vary very much, as might be expected in a group of affections whose nature is very imperfectly understood, and which may arise from many different causes.

The tremors of paralysis agitans probably signify a senile or some similar failure of the motor cortex, and are not likely to be cured by electricity. The tremors of metallic poisoning are not so commonly met with as to be likely to come under electrical treatment very often. The electric bath, with sinusoidal current, quickly cured the only case of mercurial tremor which has come under my notice (see § 170).

In cases of tremor of the arm and hand, and of the leg after local injury, and in cases of spasm and contraction of fingers after sprains of the wrist, seven cases in all, five were relieved by electrical treatment ; some by means of electrostatic sparks, others by the use of the constant current, with the anode to the affected muscles.

Tremors, and spasms affecting hemiplegic limbs, are not favourable cases. In a case of tremors of this kind in a child of eleven, in whom partial hemiplegia came on during typhoid fever, the electrical treatment of the brain, for a long time carefully tried, has yielded no result. So with spasm in hemiplegics, electrical treatment even for long periods of time is of little use.

Hysterical tremors and spasms are also common, and they do not invariably yield to electricity, though a good result may be expected in about half the cases. For them the electrostatic methods are the best. Two out of three cases of facial spasm were definitely arrested by electrical treatment, both were in women, aged 44 and 47 respectively. In a third patient, a man aged 30, who had suffered for three years, the treatment was of no use. Applications of the anode, stabile, are recommended.

Wry-neck, from contraction of the sterno-mastoid, has been relieved in less than half the cases.

It must not be forgotten that spasmodic affections are not infrequently reflex phenomena, thus there may be severe spasm of the muscles of mastication from inflammation about the gums or throat, and inflamed cervical glands sometimes cause wry neck. Or there may be spasm from direct irritation of the nerves as in wry neck from disease of the cervical vertebræ. Before commencing electrical treatment a careful examination should be made for any source of irritation, and this, if possible, must be remedied.

In children, and also, though less commonly, in adults, wry neck may be due to exposure to cold or wet, and this form has been called "rheumatic," and yields easily to simple measures. Muscular spasms are also common in hysterical and emotional people, and in such they may come on quite spontaneously or as a sequel of some slight injury or illness. Apart from hysteria we often find that various forms of spasm, and especially wry neck, have been brought on by prolonged mental anxiety.

Facial spasm is not uncommon in its slighter degrees, in the form of twitchings of some of the facial muscles. Sometimes the twitchings are very frequent and severe, and though at first they can be controlled by an effort, they may in time become quite uncontrollable. The commonest form of spasm, however, is wry neck, tonic or clonic. The sterno-mastoid is usually at fault, but occasionally the wry neck is produced by contraction of the splenius capitis or the trapezius.

Very often no cause can be found for the wry neck, and perhaps it is most obstinate in these very cases. Electrical treatment has been often tried for spasmodic affections, and it is very successful in some, but fails completely in most. In hysterical cases, the dry brush

or electrostatic sparks may always be tried with good prospects of improvement. In the other cases the battery current is better, the stabile action of the anode being employed with currents of 10 to 20 milliampères over the affected muscles and its nerves. Erb has recorded twenty cases of spasm in various muscles, almost all of which were cured by electrical treatment; a few of them improved only after a very large number of sittings, but others were very promptly cured by three or four.

183. **Writer's cramp.**—This is the best known form of a series of spasmodic affections which are produced by prolonged over-work of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasm or occupation spasm has been given to this group. Besides those whose occupation is writing, violinists, piano-players, tailors and shoemakers, are subject to similar attacks in the muscles which they use most often. In writer's cramp there is a combination of muscular weakness, tremor, pain, and spasm; either of these may predominate, the first and chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and in the first dorsal interosseous; if the occupation be persevered with, other muscles are called in to take the place of those which are deranged, and soon they also suffer.

The characteristic feature of these affections is that the weakness, or pain, or spasm, is produced only by one particular kind of work. The hand of a man with writer's cramp remains quite useful to him for everything except for writing, and so with the other forms of true occupation spasm.

It is only in advanced cases that the symptoms are

provoked by other uses of the same muscles. When symptoms resembling those of writer's cramp are produced by any sort of movement involving the use of the affected muscles, some other explanation of them should be carefully looked for, as the case may turn out not to be a true case of writer's cramp.

I have notes of twenty-six cases of writer's cramp, four occurring in women. Pain, tremor, and numbness, are the symptoms most commonly complained of. Spasm is only noted in eight. The hand and forearm are the usual seat, though in one the symptoms consisted of pains confined to the shoulder, and weakness and slowness in writing. One patient gave up writing and became a maker of foot rules, but after two years of this carpenter's work he found similar symptoms returning to the muscles most employed. Another patient, a woman, gave up writing and became a nurse, but a year and a half later she returned, for being out of employment she began writing again, and the writer's cramp returned. Thirteen cases are reported as cured.

Of other forms of occupation spasm I have notes of fifteen cases, four in women, their occupations are very varied, but in all there was a severe strain upon some muscles of the hand; eight are reported cured; in one, a violinist, the spasm affected the ring and little fingers; in a pianist it was the left hand which failed.

Electricity is of value in this disease, but it must be helped by the complete abandonment for a time of the habit which has caused the development of the disease. The constant current, without sudden breaks, is to be used; currents of ten to fifteen milliampères if the patient can bear it. The skin and the electrodes to be thoroughly moistened with warm water. Different

writers prefer different positions for anode and kathode, thus Dr. Poore* places the anode in the axilla, and the kathode over the ulnar nerve just where it leaves the biceps on its way to the olecranon. The patient is also made to exercise the interossei by separating and approximating the fingers rhythmically. Another plan recommended by the same writer is to place the anode over the median nerve at the inner border of the biceps, and the kathode over the body of the flexor longus pollicis, while the patient is made to flex rhythmically the distal phalanx of his thumb. Other similar plans, including the combination of a descending current, with rhythmic exercises, may be used.

Max Weiss† in discussing the electrical treatment of writer's cramp, points out that three conditions may be found in these cases. (1) Spasms; (2) tremors; (3) paralyses; and sometimes combinations of these morbid states. In the spasmodic cases which are usually tonic rather than clonic, on taking up the pen, the thumb, index and middle fingers, and especially the thumb and index, pass into a state of tonic spasm. He considers that the disturbances are situated in the median and ulnar nerves, not in the motor cortex nor in spinal cord. The treatment he recommends is the use of constant currents of from two to five or eight milliampères, for fifteen to twenty-five minutes, with absolute rest from writing; applications twice daily during the first weeks, afterwards diminishing to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck, or on the upper and

* "Electricity in Medicine and Surgery," 1876. *Medico-Chirurgical Transactions*, 1887.

† *Centralblatt fur die gesamm. Therap.*, April, 1891.

inner part of the arm. Anode may also be applied to the tender points for ten to twenty minutes.

Generally speaking, the anode should be employed at the seat of the symptoms, the kathode being placed centrally, over the first part of brachial plexus, or on the upper dorsal spine.

Dr. Poore's preference for a descending direction of current, is probably due to the intention of setting up the "refreshing" effect upon the nerves and muscles of the limb (§ 123).

In Dr. Poore's later article on writer's cramp he has shown that a certain number of the cases have signs of some slight central lesion, either in brain or cord. There may be altered irritability in the affected muscles, and tenderness of the nerve trunks. It is possible that some neuritis may be present in some of these patients.

Monell has advised static treatment for writer's camp and claims to be able to cure the condition without any interference with the occupation of the patient.

184. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The peculiar spasms can be evoked by compression of a nerve trunk or of the main artery of a limb, or by a rough touch over a motor nerve. Erb* first showed that the electrical irritability was also increased in this disease.

* *Arch. f. psychiatric*, 1874.

In a recent paper Dr. Bernhardt* has reported three cases in which the electrical reactions were examined, his results compared with the normal irritability of the same nerves are represented in the following table, which gives the current in milliampères required to produce the first KCC contractions.

NERVE.	NORMAL.	TETANY. 3 CASES.
Facial	0·9—3 milliampères	0·5 —1·5 milliampères
Median	0·9—3·3 ,,	0·25—1·5 ,,
Musculo-spiral .	2 —5 ,,	0·25—1·0 ,,
Peroneal . . .	1 —2 ,,	0·5 —1·1 ,,

ACC and KDT (kathodal duration tetanus) were also more easily produced than usual. In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of sudden anodal opening. The results of treatment are said to be entirely favourable, but the disease is one which tends to disappear spontaneously.

185. **Exophthalmic goitre.**—Quite a large literature has grown up on the electrical treatment of this disease. Many favourable cases have been reported with various kinds of electrical treatment. So long as the pathology of the disease remains uncertain, the electrical treatment must continue to be tentative. It is by no means successful in all cases, although numerous cures have been reported in the journals.

* *Berlin Klin. Wochenschrift*, June, 1891, No. 26.

It has been assumed that the seat of the disease is in the vaso-motor system, and especially in the cervical sympathetic. It is important to bear in mind, as has been pointed out by Gowers, that the sympathetic system is represented in the brain, and on this account the treatment should not be confined too strictly to the region of the neck.

In this country Cardew reported* a short series of cases where the constant current produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced, the enlargement of the thyroid was diminished, and the nervous condition of the patient was improved. He suggested that the treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advised that a current of two to three milliampères should be applied for six minutes; the anode to the region of the lower cervical spine, the kathode to the side of the neck, labile, from the mastoid process to the clavicle. The two sides of the neck should be treated alternately, and the patient should persevere with the treatment for two months at least. He also declared that the diminished resistance of the body, which has been observed in this disease, is due simply to the increased perspiration and moisture of the skin, and this opinion is now generally accepted.

Owing to this lowering of resistance a small electromotive force is sufficient to give the required strength of current. The number of cells in circuit must therefore be small, commencing with as few as three or four, and the galvanometer readings must be carefully attended to.

* *Lancet*, July, 1891.

General stimulation by means of the electric bath can also be tried. In my own experience I have never seen a cure of Graves' disease by electricity.

186. **Migraine and headache.**—The results of treating migraine electrically are sometimes encouraging, and at others quite disappointing.

In severe and typical migraine there is not much use in trying to dispel an attack by electricity. In the slighter forms of one-sided headache, the pain may be immediately and permanently relieved by treatment with the constant current, the anode being applied to the seat of pain; the headaches of constipation are not usually improved in this way.

The electric breeze to the scalp has a very agreeable effect in headache, and the relief it affords is sometimes permanent, though at others it is only temporary. Cases have been reported in which a prolonged course of electrostatic charging has been followed by the disappearance of the tendency to attacks of migraine.

187. **Mental diseases.**—Some work has been done in the treatment of the insane by electricity, chiefly by means of the application of the battery current to the head. It is also certain that general electrification by the sinusoidal or coil bath is very useful in many of the slighter cases of melancholia, by improving the metabolic activity of the tissues. See also § 173 for a valuable report of the results of treatment by the coil and bath in cases of this kind.

CHAPTER XII.

The Spinal Cord and Nerves.

The spinal cord. Treatment of paralysis. Infantile paralysis. Progressive muscular atrophy. Injuries of nerves. Special nerve injuries. Neuritis. Neuralgia. Sciatica. Anæsthesia. Nerves of special senses.

188. **The spinal cord.**—Treatment may be directly applied to the spinal cord by means of electrodes placed upon the back over the vertebral column. In this way currents can be made to traverse the spine in a longitudinal direction. When the effect is to be localised at one particular level the indifferent electrode should be large and placed on the front aspect of the trunk, while the other is applied to the back at the position required. Direct treatment of the cord has been carried out for the relief of certain chronic disorders, and favourable cases have been reported by Erb and others in locomotor ataxy, in concussion and other injuries of the spine, in progressive muscular atrophy, lateral sclerosis, and chronic myelitis.

The systematic electrical treatment of diseases of the cord requires very much more study before it is likely to be accepted by the medical profession as a treatment of real value. In spite of the fact that a certain number of successful cases have been reported, the effect of electrical treatment upon these spinal cord diseases is usually negative. In acute myelitis electrical treatment should be avoided as it is likely to do harm.

The results of treating locomotor ataxy and progressive muscular atrophy have hitherto for the most part been negative; where locomotor ataxy has been said to have been improved or cured, the diagnosis may have been erroneous, and the symptoms may have been due to neuritis. See also § 191 and § 192 for further details. It is important to distinguish between the statement that the results of treatment are negative, and the quite different statement that electrical treatment is useless in these complaints. It is just possible that further study may justify the belief of certain good observers that something may be done by electricity to arrest the progress of these chronic spinal cord diseases.

189. **Treatment of paralysis.** — Certain fundamental principles of treatment apply to nearly all cases of paralysis. If possible there should be treatment of the seat of disease, brain, cord, or nerves, as the case may be, and also treatment of the paralysed muscles. The seat of disease is to be treated in the hope of setting up trophic or vasomotor changes there, in order to remove the cause of the paralysis, if it be possible to do so, and the muscles are to be treated in order to maintain and stimulate their nutrition. Stimulation of the peripheral parts also acts usefully by influencing the central organs through the medium of the sensory nerves, and in a reflex manner may set up motor impulses along the nerves to the paralysed parts. When the paralysis is purely motor, and the sensory functions of the affected parts are normal, this reflex mode of stimulation is of importance, and it follows that peripheral excitation of a limb in infantile paralysis, or of the face in Bell's palsy, is a rational procedure.

When a nerve trunk has been injured and repair is taking place, it is often noticed that voluntary power

returns before the return of electrical reactions in the nerve and muscle. Here direct treatment of the nerve trunk, by applying the electrodes to it above the seat of injury, or indirect treatment through the agency of reflex stimulation of its centre may prove useful. Erb says:—" A hindrance in the motor conduction, which cannot be overcome by the will, may perhaps be conquered by a stronger artificial stimulation, and the way thus made clear for voluntary excitation. Hence, if we allow the electric irritation to act energetically above the seat of lesion, the hindrance may perhaps be in this way removed."

When the battery current is used the paralysed muscles are to be treated by applications of the kathode, which must be well moistened and moved slowly and firmly over the affected muscles; the current to be between five and ten milliampères, and the duration of treatment ten minutes. It is important not to use electrodes which are too small. A two inch size (five centimetres) is suitable, and less painful than smaller sizes, because the density of the current at its surface is less. If five milliampères should seem to be painful in the case of a child the current must be reduced; when the skin is well wetted the painful effect of the current is diminished. In addition to the labile applications the current may be opened and closed or even reversed suddenly from time to time, for the sake of exciting contractions in the paralysed muscles. The indifferent electrode is to be placed over the spine in the neighbourhood of the central lesion.

When the induction coil is used a similar method of application may be adopted, the current being carefully regulated so as not to produce discomfort. Or both poles may be applied to the affected part, one being

buckled round the limb in a position close to the nerve trunk, while the other is manipulated over the muscles, or lastly, both electrodes can be applied direct to the muscle. If the muscles do not respond to the coil it has been customary to use the battery current, although in such cases the induction coil may give results which are quite as good, or better. It must be remembered that the difference between the induction coil current and the battery current applied in a labile manner is only a difference in degree, one giving frequent and sudden variations of current, and the other infrequent and gradual variations. I have seen large numbers of cases with the reaction of degeneration who recovered under treatment by means of the induction coil alone.

The continually expressed opinion that for muscles showing the reaction of degeneration the induction coil is useless is a belief based more on theory than on practice. The every day experience of those who are occupied with electro-therapeutics is completely against it. The results obtained by Duchenne from induction coil currents are a sufficient testimony to the value of this mode of treatment in all kinds of paralytic affections.

It is true that a muscle showing the reaction of degeneration will contract to the constant current only, and in so far as the contraction of the muscle is a good thing for the muscle, the constant current may be better than that of the induction coil; but it is absurd to think that the amount of benefit can be measured by the amount of contraction set up in the muscle. A muscle which is completely and permanently cut off from its nucleus of origin will continue to degenerate and waste, however persistently it be made to contract by treatment with the constant current. This matter of the relative

advantages and virtues of constant and interrupted current dates from a long way back. Each has been warmly advocated by its partisans to the exclusion of the other since the days of Duchenne and of Remak.

But in paralysis any form of electrical application is of value, chiefly, if not entirely, as a means of stimulating the activity of the living tissues of the part under treatment; with the constant current of a battery the stimulation is chiefly obtained when the current is made to vary whether by interruptions or reversals, or by movements of the electrode over the surface, while with the coil the variations are produced by the apparatus. So far as the action of electricity upon the growth of muscle is concerned, the experiments of Debedat* are interesting, as they prove the superiority of the induction coil for stimulating the growth of muscle.

He reported the results of experiments made on the muscles of young rabbits with the various kinds of electric stimulation used in medical treatment. The experiments were made on the group of hamstring muscles; those of the left side were stimulated in various ways daily during twenty days, for four minutes a day; those of the right side were left for purposes of comparison. At the end of the period the animals were killed, and the muscles of the two sides carefully removed and weighed; portions were also hardened and examined microscopically. The modes of stimulation were as follows:—1. The induction coil current, lasting for one second, and followed by one second of interval, and so on for four minutes. 2. The battery current of two milliampères, with the same periods of stimulation and repose. 3. Electro-static sparks two to three millimetres long, repeated every two seconds. 4. Tetan-

* *Arch. d'électricité médicale*, February and March, 1894.

isation of muscles for four minutes by means of an induction coil, without any intervals of repose. 5. Steady galvanic battery current for four minutes without intervals of repose. The results showed a gain of 40 per cent. in weight on the stimulated side with the rhythmic induction shocks, and of 18 per cent. with the rhythmic battery current. The effect of the static sparks was *nil;* the prolonged tetanisation caused a loss of weight; the prolonged steady battery current a slight increase in weight. Adhesions had been formed between the skin and the muscle at the points of application of the electrodes in this last. The gain in weight was due to a true growth of the muscle; the loss was accompanied by histological evidence of damage to the muscle fibres. The author concludes that the most advantageous mode of promoting the growth of muscle by electricity is to use an induction coil, and to arrange the periods of contraction and repose of the muscle so as to approximate to the conditions of a muscle during the performance of rhythmic gymnastic movements—namely, about thirty periods of contraction and thirty of rest per minute, prolonged tetanisation being distinctly hurtful.

These experiments are of great value as they indicate clearly the best method of carrying out treatment, when the nutrition of a muscle is the object desired.

Whenever children are to be treated by electricity great care must be taken not to frighten them by sudden shocks, the current used must never be so strong as to alarm them or make them cry, and it is important that the apparatus should work very smoothly and evenly. Many coils are defective in the matter of contact breaker; until lately there has been little attention given to it, and any sort of vibrating spring has

been thought good enough, but there is a very great difference between a good and bad one.

190. **Infantile paralysis.**—There is no doubt that electrical treatment is of the utmost value in this disease. The long lasting paralysis and atrophy which it so often leaves behind is apt to be discouraging, but once a regular system of electrical treatment has been instituted a gradual improvement soon becomes perceptible. As the result of an electrical testing which has shown seriously impaired reactions, many people have been told that their children were beyond reach of treatment, although it is quite certain that prolonged electrical treatment will do good to nearly all cases of infantile paralysis, particularly if not more than a year or two has been allowed to go by since the incidence of the disease. Even after that lapse of time much may still be done.

There is a formula in which the prognosis of infantile paralysis has been commonly summed up. It is as follows:—If the ganglion cells supplying the muscle are destroyed recovery must be impossible, and if the cells are not destroyed treatment is unnecessary, because the patients will get well of their own accord. This formula, I am sure, has done a great deal of harm, for it is widely accepted because it saves such a lot of trouble. But it starts from the assumption that the disease must either destroy all the motor cells of a muscle or else must leave them all uninjured, and this assumption is certainly not correct. On the contrary, the damage to the motor cells may be of any degree of severity or of any extent, and the paralysis may vary between slight weakness and complete loss of all motor power.

It is reasonable to suppose that a focus of disease in the anterior cornu of the cord may destroy some of the

nerve cells of the nucleus of origin of a muscle, while others in the same nucleus may escape, and this might especially be the case if the nucleus of origin is an extensive one. On this point the statements of Sherrington are conclusive. In the *Medico-Chirurgical Transactions*, vol. 82, p. 456, he writes:—"The position of the nerve cells sending motor fibres to any one skeletal muscle is a scattered one, extending throughout the whole length of the spinal segments innervating that muscle; in the limb regions many muscles receive their motor fibres from as many as three consecutive spinal roots, and the bodies of the nerve cells innervating those must therefore, inside the cord, extend through the length of three whole segments of the cord as a continuous columnar group, and in each transverse level of the cord these cells must lie commingled with nerve cells innervating many other muscles. Hence no traumatic injury of the spinal cord can ever paralyse a single muscle alone and apart from others."

This being so one can readily understand how a muscle may be partly crippled by poliomyelitis and yet may retain partial voluntary power through the support of such of its ganglion cells as happen to survive. There is also the possibility of neighbouring cells taking up the work of those destroyed. The object of electrical treatment then is to stimulate and develop any surviving muscle fibres, and if possible to make them numerous enough and strong enough to form an useful muscle.

Duchenne long ago pointed out that a muscle crippled by infantile paralysis may still contain a few living functional muscle fibres, and that these may easily be overlooked in an ordinary electrical examination of the muscle, but that they can be successfully cultivated by

persevering treatment. There is no doubt that cases admitting of similar interpretation do occur, for example, I have seen a quite respectably sized mass of calf-muscle develop in a limb which for two years at least had shown no trace of electrical reaction of any sort in that region, and the same in other muscles, notably in a deltoid muscle which, after remaining for nearly three years completely atrophied as the remnant of an extensive paralysis of the upper arm, eventually began to grow, and to show faint contractions of normal quality to the induction coil. It is an interesting point that the new development of the calf just mentioned has taken place almost entirely in the outer head of the gastrocnemius. In another case in which the deltoid was paralysed, there now is good growth in its posterior third, and there only.

If the surviving fibres can by cultivation be made numerous enough to have some useful voluntary power, they will be able to maintain themselves in a way which is impossible to them if they are unable to do any work. I have had an opportunity of testing and dissecting the muscles in an amputated leg the seat of severe infantile paralysis of old standing. The age of the patient was 20 years, and the limb had been diseased from childhood. The muscles of the leg were all extremely atrophied, degenerated and fatty; in fact, the calf was almost like adipose tissue, but still contained a sufficient number of normal muscle fibres to show visible contractions to the induction coil current. The other muscles of the leg though in a state of advanced atrophy, all contained fibres which were able to respond either to the induction coil or to the battery current. The intrinsic muscles of the foot were normal. These reactions showed, to my mind, that even at that

time there must have been some surviving ganglion cells in the affected portion of the cord, and that a certain degree of trophic nervous influence was still available for the muscles of the paralysed limb.

The persistence for several years of even a reaction of degeneration implies, I believe, that the muscles showing it are not wholly cut off from their spinal centre. When there is complete division of a nerve trunk, the muscles cease to react at all to electricity in a year or less, but in infantile paralysis a well marked reaction of degeneration may be demonstrated ten or twelve years or more after the original attack; here then, clearly is a distinction between the condition of a muscle cut off completely from its nucleus of origin by section of its nerve, and a muscle paralysed and wasted by severe poliomyelitis.

Again a muscle which has been for a time without any kind of reaction may develop a reaction of degeneration at the time of its commencing recovery. This may occur after the reunion of a divided nerve, (see § 193 for a case) or in poliomyelitis; and it seems to suggest that there may be "trophic cells" as distinguished from purely motor cells and that in infantile paralysis the trophic cells may not always suffer in the same degree as the motor cells, and that fibres from the trophic cells may have a greater power of regeneration after injury than is possessed by the purely motor cells and so may lead to the occasional restoration of modified reactions (RD) in advance of voluntary power or normal reactions.

Among the muscles damaged by infantile paralysis three degrees of injury may be noted. In one the muscles are thin, but they present reactions, which though weak are normal in quality both to the induc-

tion coil and to the battery current. In the second group the muscles are paralysed, atrophied, and show a reaction of degeneration, while the third group show no visible reactions at all.

It cannot fairly be said of the first group that they will recover spontaneously, for there are many which do so very imperfectly. Under treatment they usually begin to progress from the first, and become much strengthened even when the affected limb has been much thinner and weaker than its fellow.

It is well known that muscles paralysed by poliomyelitis may recover spontaneously, but there are many others which remain in a state of very imperfect recovery, even though their electrical reactions are normal, and these derive benefit from systematic electrical treatment. I have seen improvement start at once with treatment in a case of fifteen years standing, previously untreated.

With cases of the second class, namely, those with great atrophy, paralysis and the reaction of degeneration it is quite a mistake to say that they are incurable, and that electricity can do nothing for them. Electrical reactions of normal quality, and useful voluntary power may return in muscles which for a long time have shown RD and loss of voluntary power, and this I have seen a number of times.

In a child with a history of paralysis which came on at the age of 4½ months, treatment commenced in June, 1891; she was then 3 years of age. There were no reactions in any muscles of either leg, there was extreme wasting, and marked talipes equino-varus in the left foot. She was quite unable to stand. After three years treatment her legs showed reactions to the induction coil in nearly all the muscles on both sides, and

she could walk, though this was done in a rather awkward manner, because one quadriceps extensor muscle continued very thin and weak. This case affords a clear instance of the good effect of electrical stimulation upon the nutrition of greatly enfeebled muscles, which at one time seemed to have fallen into the last degree of atrophy and paralysis.

I have notes of numerous cases in which normal reactions and voluntary power have returned in muscles long paralysed with RD.

The following illustrates the class of case:—

C. F., onset of paralysis in 1894, when seen in the same year there was RD in front muscles of right leg, with feeble normal reactions in the peronei, and no reaction of any kind in calf or tibialis posticus. Next year there was slight return of voluntary power. In 1899 voluntary power much greater, and normal reactions of good quality in peronei and front muscles with return of reaction (RD) in calf and tibialis posticus.

The routine treatment with infantile paralysis should be as follows:—At the first visit the muscles are tested carefully and the result is recorded, the girth of the affected limb is measured, and the voluntary power of the paralysed muscles ascertained, and any faulty attitude of the limb noted. A note must also be made of the colour of the limb, its temperature, and whether chilblains or scars are present or not. The mother or the nurse is instructed how to carry out the electrical treatment with coil bath, and she is further told to rub the affected limbs every night for a quarter of an hour. If irons or other orthopædic appliances are worn the child is to be made to exercise its limbs without them for a certain time every day. She must also be shown how to exercise the muscles which are weak, by means

of appropriate movements, and must take pains to make the child try to do its best to move the limb accordingly. By impressing upon the parents the need for patience and perseverance, one is able to ensure their co-operation, and this is the most important factor of all. The nurse or mother must carefully be taught how to regulate and manage the coil. The induction coil is the best instrument for use in these cases. In addition to the coil bath a short application to the weakest muscles by means of electrodes may be advised when the management of the case is in intelligent hands. The coil or the battery current can be used for this as may seem most advantageous and it is best that this part be reserved for the medical man's own application. A constant battery is not very suitable for domestic use. The medical man must make periodical testings and examinations to see how the case progresses.

The first signs of improvement are a better circulation in the affected parts, disappearance of chilblains and sores, and a gradual gain of voluntary power.

The return of electrical reactions comes later, and it is common when all contractility has been lost for the normal reaction to the induction coil to return without an intermediate stage of contraction to galvanism only. This means that the few latent normal fibres in the wasted muscle have begun to grow and gain sufficient strength to produce a visible contraction.

When the lower limbs are the seat of the paralysis the electric bath is a much better method than direct applications of the electrodes to the paralysed muscles. An ordinary wooden tub of appropriate size filled with warm water is taken, the electrodes in the form of plates of metal are suspended at the two ends, and the child dressed in a short waistcoat, is put into the bath

in a sitting position. The current is very well borne in this way, and the whole extent of the paralysed parts comes simultaneously under treatment. The strength of the current is gauged by putting the hands into the tub, one at each end, and by watching the effect upon the child, the current being weak at first, and strengthened gradually. It must not be so strong as to cause rigidity of the muscles. This plan requires no special knowledge of anatomy, it is efficient and likely to be persevered in, and this point of perseverance over long periods of time is the key to success. Even if only one of the lower limbs be affected, there is no reason why the bath should not be used, and if the sound leg be flexed and drawn up, most of the electrical current can be diverted into the affected one. From Debedat's observations (§ 189) one would advise that the current be interrupted rhythmically at intervals of one or two seconds. A very ingenious rhythmic interruptor driven by clockwork has been designed by Prof. Bergonié, and is made by Gaiffe of Paris.*

The following summary represents the writer's views upon infantile paralysis :—

1. In every case of infantile paralysis which is not clearing up satisfactorily, it is important to apply electrical treatment, continuing it for six months or a year or more.

2. It is the exception for a muscle to be so completely destroyed by poliomyelitis as to be left without any functional fibres, and these remaining fibres can be cultivated by persevering stimulation of them.

3. Where the muscles show only the reaction of degeneration or are even entirely abolished, some improvement may be hoped for.

* *Archives d'élect. méd.*, 1896, p. 66.

4. The amount of restoration which is possible in a muscle will depend upon the number of surviving ganglion cells. With patient treatment recovery advances very much farther than one might expect, and is infinitely superior to the results obtained when treatment has not been given.

5. Even where the electrical reactions are not altered in quality, it is not good practice to leave the case to take care of itself.

In electricity we have a stimulating treatment, which is superior to any mechanical stimulation by rubbing or massage. It may advantageously be combined with these. The form of electrical stimulation to be employed is less important than the need for perseverance. As a rule the induction coil meets the requirements of the case, and when used in conjunction with the bath is quite easily arranged for use by the mother or nurse of the patient.

The distribution of the paralysis produced by acute anterior poliomyelitis is peculiar, some muscles are affected very much more commonly than others.

In the first place the lower limbs are the seat of paralysis more often by far than the upper. In the lower limb the muscles of the leg are very frequently damaged, especially the peronei, the tibialis anticus, and the calf muscles; the quadriceps extensor cruris is also rather apt to suffer; and if the paralysis affect all its parts seriously, the whole limb becomes very much crippled thereby. Except when there is extensive damage to the limb the intrinsic muscles of the foot are likely to escape, and the same can be said of those of the hand.

In the upper limb the muscles of the shoulder and arm suffer rather frequently. The deltoid is often in-

jured, and the loss of it cripples the arm very much, and it is also a muscle which does not readily improve.

The deformities which result from the over action of muscles, when their antagonists are damaged by this disease, are well known. Many of the various forms of club-foot originate from infantile paralysis. It may be worth while to give briefly the action of the leg muscles upon the foot as summed up by Duchenne:—There are three pairs of muscles with the function of moving the foot upon the leg. 1. The calf muscles and the peroneus longus. 2. The tibialis anticus and the extensor communis digitorum. 3. The tibialis posticus and the peroneus brevis. The first pair extend the foot, the second pair flex the foot, and the last pair produce lateral movements.

The movements of flexion and extension by the first groups include lateral movements also, because the pull of the muscles is not direct. When simple flexion or simple extension movements are required, they are produced by the combined action of both components of each pair; thus, the calf muscles extend and adduct, while the peronei extend and abduct, the tibialis anticus flexes and adducts, the extensor communis digitorum flexes and abducts. Of the remaining pair, the one, the tibialis posticus, adducts, and the other, the peroneus brevis, abducts. There are many other composite movements carried out by these muscles, but individually considered their actions are those just mentioned. The special deformities likely to follow the paralysis of any of these muscles, or of any combinations of them, can be predicted, if their special action, and that of their antagonists, are borne in mind. Operations for the correction of the deformities produced by infantile paralysis by means of attaching the tendons of impor-

tant paralysed muscles to the muscular portions of less important and unparalysed neighbouring muscles have been successfully performed. Some of these muscles play an important part in preserving the arch of the foot, and when they are paralysed a tendency to flat foot is well marked. An opposite condition of exaggerated arch of the foot is also known, and was described by Duchenne under the name of *griffe pied creux*, or hollow claw foot. Often it is an effect of paralysis of the interossei.

These muscles flex the proximal phalanx and extend the distal phalanges of the toes by a single movement, they also produce lateral movements of the toes. Their action supplements those of the other flexors and extensors of the toes. The long flexors flex only the distal phalanges, while the extensors, extend only the proximal phalanx. In the absence of the antagonising action of the interossei the long extensors extend the first phalanges permanently, and the long flexors flex the second and third phalanges also permanently, and this produces a claw-like attitude of the toes. The abductor and flexor brevis of the great and of the little toes act in a similar way, and when they are paralysed the claw shape becomes more intensified.

The hollow claw foot or *pes cavus* is not very often developed as a sequel to infantile paralysis, if it does, it is generally unilateral. Cases of double *pes cavus*, from their history and the associated symptoms, seem to be probably due to spasm of the long flexors and extensors of the foot and not to paralysis of the interossei (see § 218 below).

191. **Progressive muscular atrophy.**—Before considering the electrical treatment of this disease, it may be worth while to discriminate between the various

states of muscular atrophy which have been formerly confounded under this name. These are "myelopathic" atrophies due to changes in the anterior cornua, "neuropathic" atrophies due to changes in the nerve trunks, and "myopathic" atrophies from changes limited to the muscles themselves. True progressive muscular atrophy is a type of the first class, and pseudo-hypertrophic paralysis of the third, while various forms of atrophy due to neuritis require to be considered in the second class. Indeed the lines of demarcation between different groups have not always been drawn with precision.

In none of the diseases included in the general title of progressive muscular atrophy can it be said that the prospects of cure by electricity are good. Still in default of any other better method of treatment it is reasonable to believe that the use of electricity is a step in the right direction, and it is quite right that efforts should be made to obtain relief by means of electrical treatment. In the spinal forms Erb considers that he has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord, particularly the cervical enlargement, which is so frequently the seat of the most severe atrophic changes. His method is to use the battery current, applied to the cervical spine, the cervical sympathetic, the lumbar enlargement and the peripheral nerves. He insists especially upon the importance of the action of both poles being brought to bear successively upon the affected regions of the cord. Finally, the affected muscles are to be treated by the induction coil current. The current should be "moderately strong," but too vigorous a treatment is not advisable.

Erb also says that although electrical treatment may arrest or retard the progress of the disease, that yet it is in no way a cure, and that the curative results said to have been obtained are generally the consequence of errors of diagnosis, especially in cases of neuritis, infantile paralysis, and atrophy after joint affections. He considers that the myopathic atrophies have a more favourable prognosis, as he has seen great benefit follow electrical treatment in long standing cases of that kind. Duchenne wrote that by means of induction coil treatment he had been able to arrest the progress of the disease in an advanced case,* to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour, a condition of things extremely likely in Duchenne's opinion to bring on a relapse. He is certain that he has seen an increase in the bulk of a wasting muscle from coil applications, but only in cases where the muscle had not altogether lost its irritability to coil currents. He lays down precise instructions for the method to be adopted as follows:—

1. To pass the moistened electrodes over the surface of each of the affected muscles, keeping them close together, and using a current of low electromotive force.

2. To stimulate the muscles moderately, and with a current which is not interrupted very frequently.

3. To treat only the muscles which react to the coil, and to pay most attention to the most important

* The case which seems to have been undoubtedly one of "myelopathic" progressive muscular atrophy, is described and figured. "Elect. localisée," 3rd edit., p. 500.

muscles, and to terminate the sitting by a mild application to any muscles which may be threatened with an invasion of the disease.*

Treatment of the spinal cord itself should be carefully tried in these cases, as the mere treatment of the muscles does not appear to be very promising.

The electrical reactions in progressive muscular atrophy are a little complicated, because the gradual destruction of the muscle, fibre by fibre, produces a condition in which, while some fibres react normally, others respond only by a reaction of degeneration. It may sometimes be possible to recognise a sluggish contraction appearing after the quick contraction, the latter being produced by the sound fibres and the former by those which are degenerated.

192. **Locomotor ataxy.**—The value of electrical treatment in this disease is not yet settled. At the same time it is certainly premature to dismiss electricity as useless in all stages of this complaint, although it is no doubt correct to say that in advanced cases of the disease electricity will not restore the tissues which have perished. A difficulty which meets one at the outset is the natural tendency of the disease to become arrested in certain cases, particularly in those which come under treatment early. Thus I have notes of a patient who had lightning pains, loss of knee-jerk, occasional diplopia, slight ptosis, and unsteadiness on closing the eyes, and in whom the existence of tabes was suspected by myself, and confirmed by the opinion of a leading neurologist. This patient returned home and was vigorously treated with anti-syphilitic remedies, and I have been informed since, on several occa-

* For the muscles most usually attacked, see Duchenne, *op. cit.*, p. 494, or Gowers' "Diseases of the Nervous System," p. 359.

sions, and at intervals of two or three years, that he has recovered good health and is leading an active life.

There was no electrical treatment in that case.

Another patient of mine, a police officer, with many signs of tabes, quickly lost his symptoms during a course of electric baths. Many writers on electro-therapeutics have been able to bring forward instances of relief to symptoms from electrical applications in tabes. In the *Arch. d'électricité médicale* of 1893, the notes of thirty-two cases are collected together from various sources by Dr. Laborde, and the whole subject of the electrical treatment of tabes is critically examined in a paper which forms a valuable contribution to the subject. His summary is that in his own experience the treatment of the spinal cord by continuous currents does not cure tabes. In certain cases it may relieve the pains, the ocular troubles, or the weakness of the limbs. Induction coil currents seem to act unfavourably. A further study of the subject is desirable.

193. **Injuries of nerves.**—In injury and disease of the nerve trunks the natural tendency to recover is strong, and stimulation by electricity certainly hastens their recovery very much. It has been said of electrical treatment that the cases which do well under it would do equally well if they had been left untreated, and this has often been the excuse for the neglect of electrical methods. Even if this assertion were true, which it certainly is not, it applies with equal force to most of the drug treatments which medical men so complacently prescribe for their patients. But it would be out of place in this book to criticise the habit of mind of medical practitioners.

The following case illustrates the value of electrical treatment in a case of traumatic neuritis of the musculo-

spiral nerve. A gentleman, by sitting for a long time in one position in an arm-chair, compressed the musculo-spiral nerve, and numbness and weakness of the hand, with wrist-drop, was produced. There was no treatment for several weeks, and there was no improvement. I was then asked to see him; he had paralysis with partial RD in all the extensors of the wrist and fingers; the supinator longus was also paralysed and there was impaired sensation over the back of the forearm and hand. The nerve trunk was tender to pressure at a point about half way up the humerus.

Electrical treatment was commenced and at the end of a fortnight the patient had gained considerably in voluntary power and appeared to be on the high road to recovery. Electrical treatment was therefore suspended. He was instructed to rub and shampoo the limb daily, and to exercise the muscles, and was told that he might expect the process of recovery to continue, even without further electrical treatment. A fortnight later he wrote saying that he had made no progress since the last visit. Electrical treatment was accordingly resumed, and again he began to improve rapidly, and was completely well in another fortnight.

Again, take the following instance of an Erb's paralysis. A man fell into a ship's hold in January, 1898, and paralysed the muscles of the upper arm. In the following year, March, 1899, he applied for relief, was seen and tested; a rupture of the 5th and 6th cervical cords of the brachial plexus was diagnosed, and an operation was performed for reunion. After the operation he disappeared from view for a time and did not return until November. There was no recovery of power. The limb hung helpless from his shoulder. He was referred to the Electrical department and a test

showed a faint reaction of degeneration in the deltoid biceps and supinator longus. In the previous March when tested before the operation there were no reactions at all in these muscles. It was judged from the return of these faint reactions (RD) that reunion must have taken place after the operation, and electrical treatment was accordingly commenced. Improvement began immediately. After three months he had gained enough to do a little work on light jobs and improvement was still in progress.

For those who are not unwilling to be convinced these cases seem to offer satisfactory evidence that the electrical treatment played an important part in "curing" the paralysis, and answer the objection mentioned above, an objection which is not always easy to meet because for obvious reasons it is difficult to combat it by direct proof.

All those who have had practical experience in the matter have seen cases of nerve injury begin to recover rapidly under electricity after having been stationary for long periods of time under "expectant" treatment.

The simplest cases of peripheral paralysis are those which follow injury to the nerve trunks. These cases are common, and are sometimes of great interest from the exercise in applied anatomy which their diagnosis affords. The shoulder and upper limb are their most frequent seat. The chief causes of injury to the nerve trunks are contusions or lacerations, compression produced in various ways, and wounds with sharp instruments. Falls or blows upon the shoulder, and dislocations of the shoulder joint commonly produce paralysis of the muscles of that region. Pressure, as from the use of crutches or from the weight of the body upon the arm during sleep, often produces paralysis of the mus-

cles supplied by the musculo-spiral nerve, and incised wounds of the forearm and wrist often lead to paralysis of the muscles supplied by the ulnar and median nerves. In all cases of this kind electricity is of great use, both for treatment and for diagnosis ; and favourable results may be expected in almost all cases unless the nerve trunks have been actually severed, or are involved in cicatricial tissue. In that case surgical measures for the union of the divided nerve, or to relieve it from its surroundings, are necessary before recovery can be expected.

From what has been said in §§ 136 to 139 it follows that injuries of nerves are likely to be followed by the reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But, as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the nerve recovers before degenerative changes have had time to follow, or indeed the injury may be of such a kind as to impair both motor and sensory conduction for a time without interfering with what may be called the trophic conductivity of the nerve trunk or setting up an actual neuritis. The partial reaction of degeneration is not uncommon in cases of nerve trunk injury.

In the examination of cases in which an injury to a nerve is suspected the anatomical details of the nerve supply must be carefully kept in mind.

The phenomena produced in marked cases of injury to nerves are loss of motor power, impairment or loss or perversion of sensation, and diminished temperature in the area of distribution of the nerve with changes in the muscles, such as simple diminution of electrical

excitability, or complete or partial RD, and trophic changes in the skin. The "glossy" skin of nerve trunk disease is well known, and easily recognised. It signifies *irritation* of the nerve trunk.

When it occurs in the upper extremity the skin of the hand and fingers becomes altered in colour and shiny, the finger ends become bulbous, and the nails defective. There is an alteration in the appearance of the wrinkles and folds over the knuckles, which can readily be recognised on comparing the affected with the sound side.

194. **Neuritis.**—The paralyses which follow wounds and injuries of nerves offer an excellent field for useful electrical treatment, and the same is generally true of neuritis coming on in the course of disease. The clinical importance of neuritis is much more clearly recognised to-day than it was a few years ago, thus justifying the words of Remak in 1860, when he wrote, "I am convinced that medical practitioners will soon recognise that neuritis is a pathological condition which occurs more frequently than is usually believed." At the present time the public are beginning to adopt the word, and to speak of their "neuritis," where formerly they would have spoken of their "rheumatism."

In the electrical treatment of neuritis the question of the choice of method turns largely upon the presence or absence of severe pain or of acute symptoms. Clinically one meets with cases of neuritis with marked paralysis and little or no pain, while in others there is much pain and little or no paralysis. In the acute and painful cases the direct current is indicated, in the less acute and paralytic cases the alternating (coil or sinusoidal). Some writers would further divide the paralytic cases into two classes namely those showing the reaction of

degeneration with loss of coil reactions and those in which coil reactions were not lost, and they would advise the battery current for the first of these and use the induction coil current for the latter class only. That view is not supported by experience and has already been dismissed in § 147 and need not now be re-opened, see also § 165 for the indications for the use of bath or arm-bath modes of application, as these are often very useful in the treatment of neuritis.

If the neuritis is a general one, or is due to a general cause, even though its manifestations are local, the bath should be chosen whenever it is to be had. Thus, the toxic forms of neuritis, as for example, neuritis from alcohol, arsenic, lead, &c., and neuritis following diphtheria, influenza or other general infections can best be treated by the general bath and the alternating or interrupted current. I have obtained the most satisfactory results in cases belonging to all these classes from the bath with sinusoidal current, and regard that form of application with the greatest favour. No doubt the general bath promotes the elimination of poisons in addition to its action upon the damaged tissues, (see also § 146).

195. **Neuritis from lead poisoning.**—In paralysis due to lead the reaction of degeneration is usually present, and is an early symptom. The partial reaction of degeneration is also often seen in some of the affected muscles, and others may show only simple quantitative diminution. Erb has pointed out that from the long duration of lead paralysis and the frequently occurring relapses, the condition of the electrical excitability may be considerably complicated. In cases of long standing the reactions become very difficult to elicit. Treatment by electricity is of prime value, for muscles which have

lost their electrical irritability almost completely may be seen to recover it under this treatment, which needs to be long continued to obtain good results. Although some writers have advised the constant current almost exclusively in lead cases, Duchenne long ago showed by practical trials that a cure can be effected by coil currents also. He stated that in lead palsy recovery will follow the treatment almost always, even if the irritability to the induction coil current has completely disappeared from the muscles.

For the ordinary type of case with wrist drop, treatment by means of the arm-bath and alternating currents is always followed by improvement, and recovery will be complete except in old broken-down patients where the affection is of old standing. In more severe cases with extensive paralysis the full length bath is to be preferred and this may be combined with direct current applications to the worst muscles. To determine which of the extensors of the wrist are affected, the patient is told to raise the forearms and pronate them. If the muscles are all three of them paralysed there is then no power of extending the wrist at all. If the extensor carpi radialis brevior can act, extension of the wrist is possible when the fingers are first flexed. If only the extensor carpi radialis longior, or the extensor carpi ulnaris, can act, then slight extension is associated with a lateral movement to the side of the acting muscle. Although the supinator longus usually escapes in wrist drop due to lead, it does not always escape. In the lower limbs the peronei seen especially prone to become paralysed.

It is extremely important when the lead poisoning is a result of the patient's occupation that he should be advised to give it up altogether, otherwise relapses are

almost certain to follow his return to work. When the patient returns to his occupation partly cured, he is almost certain to relapse.

196. **Arsenical neuritis.**—General neuritis may be produced by arsenic in medicinal doses or it may follow a single large dose. As an instance of the latter the following is of interest. A prison warder in Ceylon was poisoned by a dose of arsenic in May, 1896. He survived the immediate effects of the poison, although they were very severe, and six days later felt numbness of the extremities which extended until there was general loss of power. He could not stand, nor feed himself nor button his clothes. The bladder was not affected. In October he came to England and could then stand and walk a little. Knee jerks were absent, reactions showed partial RD in many muscles of the lower limbs. Upper limbs normal in quality. He was treated by general electrification (sinusoidal baths) and quickly responded; but it was not until June of the following year that he was fully recovered. He is noted to have shed the nails of his toes several times during his illness.

A case of poisoning from arsenic given medicinally is the following:—A girl aged 10, with chorea to whom arsenic had been given in ten minim doses for five weeks, became paralysed in all her limbs. The legs were most affected and the front muscles more so than the calf or peronei. RD was present. There was great wasting, some pigmentation of the skin and great pain in the limbs. She made a good recovery, the girth measurement of the calf increasing by two and a half inches between March and November.

Dr. Colman* has reported a similar case, also in a

* *British Medical Journal*, January, 1898.

girl of twelve years who was treated for chorea with arsenic during a month, the daily dose being equal to forty-five minims of liquor arsenicalis. At the end of that time the chorea had ceased and the child seemed in good health, but a fortnight later she had complete paralysis of the extensors of the feet, with RD, and partial paralysis of the extensors of the wrist and fingers with simple decrease but no RD. She recovered under the influence of rest, massage and electricity.

197. **Alcoholic neuritis.**—General electrification by means of the bath and sinusoidal or induction coil current gives excellent result in these cases. I have notes of several severe and typical cases in women where the patients at the commencement of the treatment were quite helpless, with marked reaction of degeneration in many muscles, but began to improve at once, and recovered good voluntary power, normal reactions and well nourished muscles during the time of their electrical treatment. It may be said of this disease, as of so many other forms of neuritis, that it has a natural tendency towards recovery provided that alcohol can be withheld and the patient managed on general principles, but this does not in any way detract from the advantages to be derived from electrical treatment, which has a most distinct effect in promoting and hastening the recovery of the lost power.

The presence of great pain in a case of neuritis is a contra-indication for brisk electrical stimulation, and the induction coil current is not so well borne as the sinusoidal when pain is marked. In these cases a direct current, either in a bath or applied by electrodes, may be used at the commencement of the course, with a change to the alternating current and the bath, beginning gently, as soon as it can be borne with comfort.

A point is soon reached when the latter form of current gives ease and relief, even though a good deal of pain and tenderness still exists in the limbs.

Besides the typical cases of alcoholic neuritis one may often observe cases of a local neuritis (traumatic or other) in which alcohol is a predisposing cause or is acting prejudicially. The influence of alcohol in delaying recovery in cases of simple traumatic neuritis may be very commonly observed (see also § 214).

In other cases it may be difficult to decide whether a neuritis is primarily due to alcohol or to some other cause, as for example, gout, for both influences may be at work in the same case.

198. **Gouty neuritis.**—What has been said of alcoholic neuritis and its electrical treatment applies with equal force to gouty neuritis. The general bath method, the local bath, or finally, the direct use of the constant current in cases with much pain, may all be employed with advantage in gouty cases. The use of local baths with lithium salts dissolved in the water has been already referred to in §§ 125 and 167. The local treatment of a neuritis due to gout is likely to prove ineffective if the patient is allowed to continue in a general gouty condition, with recurrent articular attacks. On this account general electric treatment is an important means even for a local gouty neuritis, and treatment by diet and by drugs must also be attended to. Some cases of "sciatica" are due to gouty or alcoholic neuritis and a reaction of degeneration may occasionally be found in them if looked for.

199. **Rheumatic neuritis.**—The term "rheumatic" has been applied to facial paralysis coming on after exposure to cold, and to other instances where exposure to cold or wet has appeared to be the direct cause of a

neuritis. Sciatica is probably in many cases a form of rheumatic neuritis. Neuritis of the circumflex nerve, the so-called "deltoid rheumatism" is another. The special methods of electrical treatment in these conditions will be dealt with under their respective headings.

Gonorrhœa has been recorded several times as a cause of neuritis. A recent case well reported, with many references, will be found in the *Arch. d'électricité médicale*, June, 1898, by Dr. Allard. The patient had loss of power in the lower limbs, impaired sensation in the same regions, with pain and tenderness of sciatic and crural nerves and showed great simple decrease to coil and to cells in the muscles of the legs but no RD. The symptoms came on a fortnight after the appearance of a discharge, and were followed a few days later by inflammation in one ankle joint. The neuritis was treated by electricity. The patient recovered.

200. **Septic neuritis.**—A form of neuritis which is very painful, and very slow to yield to treatment is that which occurs in parts which have been the seat of suppuration, and is not uncommon after whitlows or poisoned wounds of the hand. The crippled condition which is left in these cases, though partly due to a matting together of ligaments and tendons, is also in part due to the existence of neuritis. Sometimes it is difficult to decide whether nerves may not have been divided in the incisions necessary for the evacuation of abscesses, and electrical testing should be called in for an answer. But although incisions may sometimes have divided some branches of the nerves and in that way may have contributed to the paralysis, it is generally possible to show by electrical testing that neuritis exists in the areas of nerves which cannot have been injured by the knife. For example with an incision

which seems to have been dangerously near the median or the ulnar trunk in the forearm or at the wrist, a testing may show that the ulnar or the median intrinsic muscles are damaged in unequal degrees. In such a case one could infer that there was no severing of the nerve trunk, and that the symptoms were due to something more distally situated. Again one may be asked whether the loss of power is due to an actual inflammatory process in the nerves, or whether it may not be due to compression of the nerves by cicatricial tissue. To answer this question one must look for signs of neuritis outside the area in which such cicatricial compression can be effective.

In painful amputation stumps we have another instance of septic neuritis, and in these cases there is often clear evidence of a neuritis extending upwards beyond the area of the scar.

The electrical treatment of these cases is slow. I have notes of several of them who have attended for a a twelvemonth before completely losing their pains. Some relief is quickly felt from the applications, which are best carried out by means of the arm bath with the sinusoidal current or the continuous current, the latter being perhaps superior to the former. Although the results come so slowly it is none the less surely. Gradually the texture and aspect of the skin return to normal, the adhesions soften and the pain diminishes progressively and disappears.

The occurrence of a local attack of neuritis in the course of diseases which are apt to be associated with septic or sapræmic states is not very uncommon. It is probable that some of the cases of neuritis described by Dr. Turney* were really of this kind. Cases have been

* *St. Thomas' Hospital Reports*, 1896, vol. xxv.

described by numerous writers. I have myself seen one, probably of this class, in which a facial paralysis developed after confinement. Its symptoms differed in several points from ordinary "rheumatic" facial paralysis. It was associated with pain and numbness in the side of the face, and recovered very slowly and imperfectly. There was no exposure to cold nor ear disease or other local mischief to account for its coming on. Again, a patient who was being treated for stricture by the passage of catheters, was taken ill with fever for which he was admitted into Guy's Hospital. On his recovery he came to St. Bartholomew's Hospital with a paralysis of the right serratus magnus which had come on during his illness. He made a good recovery. This case I believe to have been a neuritis of septic origin affecting the posterior thoracic nerve.

201. **Neuritis from syphilis.**—Neuritis is sometimes met with in syphilis, and the following is a striking case:—A man came under treatment in December, 1892, with partial paralysis in the right arm. There was marked wasting of the biceps, and the grasp was much diminished in power. He had pains on the inner side of the arm. On his chest was an indolent late syphilitic patch of ulceration. In two months he had recovered, but not long afterwards he returned with sciatica, and a few months later came again with a recurrence in the other sciatic nerve. In 1894 he reappeared with facial paralysis. Finally, in 1896, he came for the last time with hemiplegia. He was in a wretched condition and had been laid up several months in a country infirmary. Since then he has not been seen.

It is difficult to estimate the value of electricity in syphilitic neuritis because the drug treatment in this

disease is of decided value. Electrical applications are probably useful, and should certainly be employed as an adjuvant in all cases.

202. **Neuritis after specific fevers, diphtheria, influenza, &c.**—These cases may show an extensive implication of nerves or only a local neuritis. It is probable that in all of them the general effect of the electric bath is useful, by reason of the general toxæmic condition, upon which they depend; but good results may be expected from local treatment when the neuritis itself is purely local. It may not be out of place to mention that neuritis is not the only nervous disorder which may complicate or follow the specific fevers. Hemiplegia, disease of the lateral columns of the cord, or of the anterior cornua may also occur, and as all of these conditions are decidedly more unfavourable than simple neuritis, it is important to make sure of the position and diagnosis in every case. Moreover, it may happen that a neuritis following a specific infection will persist in the most obstinate way in spite of all treatment. They do not all clear up quickly and thoroughly. For example, I would mention a case of simple neuralgia of one anterior crural nerve which followed an attack of influenza and only wore away gradually and slowly, apparently uninfluenced by treatment, and took a twelvemonth before its complete disappearance. Happily such unfavourable cases are not the rule.

After typhoid fever a local neuritis is not very rare. It is possible that some of the slighter cases of local neuritis after severe illness may be of the nature of pressure paralysis or sleep paralysis (see § 214).

203. **Neuritis as a disease of women.**—Neuritis has been noted as coming on during pregnancy, and also during the puerperal state. At the menopause also,

symptoms of neuritis, especially numbness, tinglings, and pains are frequently complained of. Dr. Turney in his paper on "Polyneuritis in relation to Gestation and the Puerperium"* seems disposed to classify the disease as a form of neuritis, due to some form of auto-intoxication. A difficulty which he fully recognises is the difficulty of excluding other causes of neuritis, but even after the doubtful or uncertain cases are separated there still remains a considerable weight of evidence in support of his views. Cases of neuritis at the menopause are not very uncommon if one is willing to accept as evidence of neuritis the symptoms of numbness, muscular weakness, &c., so often complained of by women at that period of life. Occasionally one meets with stronger evidence in the shape of muscular atrophy, though this is not common. Many female patients between forty and fifty years old are referred to the electrical department every year for treatment for pains, numbness and weakness affecting the hands, a condition which we are now accustomed to recognise as a neuritis due to the menopause. Under the arm-bath treatment they recover after a longer or shorter time.

204. **Special paralyses. The ocular muscles.**—Paralysis of these muscles may be treated by electricity. Occasionally from exposure to cold a paralysis of some of the ocular muscles is set up of a similar nature to the ordinary "rheumatic" facial paralysis.

Treatment is complicated by the difficulty of reaching the muscles. Their deep-seated position, the proximity of the retina, and the sensitiveness of the conjunctiva all help to make it practically impossible to excite contractions in them.

It has been proposed to use a fine electrode and in-

* *St. Thomas' Hospital Reports*, vol. xxv.

troduce it into the conjunctival sac after that has been rendered insensitive by cocaine. Good results have sometimes followed a longitudinal treatment of the skull, the kathode being placed stabile upon the closed eyelid. A current of 1 to 5 milliampères, and a duration of 30 to 60 seconds, are recommended by Erb. Dr. Buzzard has recommended the use of the index finger covered by damp muslin as the active electrode (see § 151, hand electrode) or small sponges may be used. They are soft and readily adapt themselves to the surface of the eyelid. The reflex effect of applications to the skin of the face may also be tried, as recommended for the treatment of facial paralysis. Dr. Buzzard has reported two cases where permanent improvement did follow the constant current. Electricity is not likely to be of much use in the treatment of ocular paralyses.

205. **Facial paralysis.**—This is a common form of paralysis, and very frequently comes under electrical treatment.

If we except those cases of paralysis of the facial muscles which form part of hemiplegia the remainder usually depend upon disease of the nerve trunk or of its nucleus of origin, and of these the commonest seat is in the nerve-trunk, and the part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct.

In this part a very little swelling of the nerve or of the walls of the aqueduct is sufficient to cause compression of the nerve fibres. Disease of the ear and exposure to cold are the commonest exciting causes.

The reaction of degeneration is present in a large number of cases of facial palsy, and a case carefully watched and treated from the commencement offers one of the best introductions to the subject of electrical

diagnosis and therapeutics, and the disease has been much studied from this point of view. The phenomena of the reaction of degeneration were first observed by Baierlacher in cases of facial palsy (see § 136). In all but the slighter cases the reaction to the induction coil disappears within the first week. If the patient is tested daily, the gradual development of the RD will be clearly seen. In testing a case of facial paralysis it is well to bear in mind that the skin of the face is sensitive, and that the muscles are near the surface, strong currents are therefore unnecessary, and must be avoided. For the importance of the electrical reactions in prognosis, see § 140. Even in the worst cases of facial paralysis of the ordinary kind, if there be no progressive disease involving the nerve, it is usual for some recovery to take place, and it is not uncommon for the recovery to take place unequally, thus the upper part of the face may improve faster than the lower or *vice versâ*. Old broken down patients do not do so well as younger people. A considerable proportion of cases of facial paralysis occurs in young women; they are excellent cases for study as they attend with the greatest diligence until completely recovered.

If a case of simple facial paralysis receives no electrical treatment its rate of recovery will be slower than if it be assiduously treated, and the same is true of cases where the electrical treatment is too feebly carried out, and this is sometimes apparent when through the timidity or sensitiveness of the patients, very weak currents are employed, and the recovery is delayed. The cases of facial paralysis from ear or bone disease, or from nuclear mischief are naturally more unfavourable than those coming on from "cold." The hemiplegic cases usually recover fairly without treatment.

Care must be taken to exclude all probable unfavourable causes of the paralysis before making a favourable prognosis. All unusual cases are to be regarded with suspicion.

The electrical treatment should be in accordance with what has been laid down for paralysis in general, viz.: direct treatment of the seat of the lesion and of the affected nerve and muscles, and reflex stimulation of the skin of the face; treatment may be commenced at once. For reaching the injured part of the nerve transverse applications to the skull are advised with the electrode behind or below the ear. Then the nerve and muscles may be treated with the kathode, each of the main branches of the nerves being stroked in a labile manner from centre to pheriphery, and each muscle being treated with the same pole for half a minute, the anode being at the nape of the neck. Lastly, the skin of the face and the muscles may be treated with the induction coil.

206. **The trapezius and sterno-mastoid.**—Paralysis and atrophy of these muscles follow injury or disease affecting the spinal accessory nerve or its nucleus. The trapezius especially may suffer as a result of the suppuration of strumous glands of the neck, or of the surgical operations for their removal.

Paralysis of the sterno-mastoid is easily recognised if looked for. When the head is turned towards the opposite side, the outline of the muscle standing out under the skin is plain to see in health but is lost if the muscle is paralysed.

When the trapezius is paralysed there is a general feeling of weakness about the shoulder, and a complaint of myalgic pains, because the muscle plays so large a part in supporting the shoulder during the movements

of the upper limb. If the trapezii be watched and studied in persons who have the neck and shoulders bare, it will be seen that these muscles are in almost continual action during movements of the arms, and, indeed, much of the beauty of the contours of the neck and shoulders depends upon the good development of the trapezii.

FIG. 73.—Paralysis of left trapezius.

When one trapezius is paralysed the difference between the two shoulders can easily be recognised, particularly if the muscle be wasted as well. On the affected side the point of the shoulder is lowered, and the line from the neck to the shoulder-tip is hollowed. This difference is well seen with the arms hanging at the sides (figs. 73, 74). The position of the scapula is

also changed, for the inner border of the bone does not lie parallel to the vertebral column, as in health, but at an angle with it, its upper corner being rather further from the middle line, and its lower angle rather nearer, at a higher level and more prominent. Duchenne has explained why this is the case. The shoulder, having

FIG. 74.—Paralysis of the upper part of the right trapezius.

lost the support of the upper part of the trapezius, hangs as it were suspended by its upper angle from the levator anguli scapulæ, and turning, as on a pivot, at the point of attachment of that muscle, its lower angle is tilted inwards and upwards, and the acromion sinks downwards by the weight of the arm. In some cases of paralysis of the trapezius this tilting upwards of the

inferior angle is not present. It may even be at a lower level on the paralysed side, particularly if the lower part of the trapezius is not completely powerless (fig. 74).

If the patient be told to raise the arms to the head another peculiar defect comes into notice; namely, that the clavicle in its outer half comes into view from behind. This is a valuable diagnostic sign of atrophy of

FIG. 75.—Paralysis of left trapezius. Clavicle seen from behind.

the muscle—one which, so far as I can learn, has not previously been pointed out, see fig. 75.

I have seen four cases in which the paralysis was due to injury or section of the spinal accessory nerve during surgical operations. In the first of these the incision was a small one, high up at the posterior border of the upper part of the sternomastoid. The nerves were

carefully considered during the operation, and, as was thought, had not been divided. The wound healed very well; nevertheless, the muscle became wasted, especially in the upper and middle parts. A small band of fibres remained in the position of the clavicular portion—the *ultimum moriens* of Duchenne—but in this there was a marked reaction of degeneration. The lower part of the muscle was not quite so much atrophied as the upper part, and the inferior angle of the scapula was not tilted upwards. In another case the whole of the side of the neck was much scarred, as the result of numerous strumous abscesses and of the surgical treatment for their relief. Both the trapezius and sternomastoid on the right side were extremely wasted, and the rhomboids were also in same condition. The scapula and clavicle seemed inclined to fall forward by the action of the pectorals, and in that position the absence of trapezius and rhomboids became evident, for the contours of the ribs could be seen behind between the scapula and the spine.

Duchenne has rather fully dealt with cases of wasting of portions only of the trapezius, and he distinguishes between the upper or respiratory portion, the middle or elevator portion, and the lower or adducting portion of the muscle. He also expresses the opinion that the upper part of the muscle will not be completely paralysed unless its nerve from the cervical plexus is damaged as well as the spinal accessory.

207. **The serratus magnus.**—Paralysis of this muscle is interesting, because the deformity which results from it is peculiar. The serratus magnus is supplied by the posterior thoracic nerve, which rises from the fifth, sixth, and seventh cervical nerves, and runs down the side of the chest behind the brachial plexus to reach the

muscle. The position of the nerve makes it liable to injury, especially in the side of the neck, and its independent course explains the reason why paralysis of the serratus magnus is frequently seen without any other muscle being affected at the same time. Occasionally the nerve to the rhomboids comes off as a branch from the first part of the nerve to the serratus, and therefore the rhomboids may be paralysed with the serratus magnus. In the first part of its course the nerve runs in the substance of the scalenus medius muscle.

The peculiar deformity which characterises paralysis of the serratus magnus is easily recognised if looked for. When the patient is examined with the arms hanging down, the shoulder may seem natural, but if the patient be told to extend the arms horizontally in front of him, the posterior border of the scapula on the affected side becomes prominent, projecting like a ridge from the level of the back, fig. 76. In a healthy person the scapula remains flat and closely applied to the thorax during this movement; the function of the serratus magnus is to hold the scapula, and especially its posterior border, closely to the side of the thorax. When the arms are extended in front, the action of the deltoid tends at the same time to throw the scapula backwards, and this is resisted by the simultaneous contraction of the serratus magnus. If the deltoid be paralysed as well as the serratus, the patient cannot extend his arm horizontally, and the deformity due to the paralysis of the serratus, cannot be brought out in the way just mentioned. In this case, if the shoulder be pushed back while the patient is told to resist, it may be found that the posterior border of the scapula can be more easily displaced on the side of the paralysis.

Paralysis of the serratus magnus is not uncommon as a result of direct injury to the nerve in the side of the neck. The following example will serve as an illustration of the usual history of such cases:—A man was using an iron bar as a lever to move heavy weights along the ground, which he did by putting the end of the bar on his shoulder, and pushing upwards forcibly

FIG. 76.—Paralysis of right serratus magnus.

against it; he felt a pain, and soon afterwards he found that his shoulder began to "grow out." When he came under observation there was marked paralysis of the right serratus magnus, and the rhomboids were also affected, which made the characteristic deformity of the shoulder even more pronounced.

In two other cases the patients had suffered severe

injuries, one having been crushed in a lift accident, in which he broke his forearm, and the other having been hurt by a heavy packing case, which fell upon him. Both of these, in addition to other injuries, had paralysis of one serratus magnus—the right. Indeed, all the cases of paralysis of the serratus magnus from injury which I have seen have been on the right side, and in male patients.

The notion is sometimes entertained that the peculiar position of the shoulder-blade described above is due to dislocation of the latissimus dorsi from its position at the angle of the scapula. This view is erroneous.

208. **The rhomboids.**—These are supplied by a special nerve, which comes off from the fifth and sixth roots. In common with the other muscles, whose nerves run a somewhat exposed course in the neck and shoulder, the rhomboids are liable to paralysis from injury. It is not usual to find them paralysed alone. When they are paralysed the posterior border of the scapula is less firmly placed than in health, and the fingers can be introduced under the edge of the bone more easily than usual. If the trapezius be well developed, it is not very easy to make out the paralysis of the subjacent rhomboids by electrical testing.

209. **The scapular muscles.**—The supra- and infra-spinati are often paralysed, as the result of blows upon the shoulder, though less frequently than the deltoid.

When the spinati are wasted, the spine of the scapula becomes prominent, and the muscles themselves can be seen to be diminished in bulk. The patient is unable to perform external rotation of the humerus in a proper manner if the infra-spinatus is paralysed; and the other external rotator of the humerus, the teres minor, is often affected simultaneously, though supplied by a different

nerve. The movement of external rotation is necessary in writing for moving the hand across the page, and in sewing the same muscles also come into play.

The nerve (supra-scapular nerve) which supplies the spinati is exposed to the risk of injury, owing to its superficial position on the shoulder. The supra-spinatus is a less important muscle than the infra-spinatus, and its condition is not so easy to determine, because it is thickly covered by the trapezius, which makes electrical testing of the muscle difficult, and its functions as an elevator and a weak internal rotator of the humerus can be completely performed by the other muscles. When the infra-spinatus is paralysed, it is usually extremely probable that the supra-spinatus is in the same condition.

The internal rotators of the humerus, namely, the sub-scapularis and teres major, have a nerve supply (the sub-scapular nerves), which escapes injury much more often than the spinati; and the same may be said of the latissimus dorsi, also supplied by a similar nerve—the long sub-scapular.

These muscles frequently escape, even in very severe injuries of the shoulder; the pectoralis major and minor also escape as a rule. Thus I have seen a patient with complete paralysis of all the muscles supplied by the brachial plexus, except the internal rotators, the latissimus dorsi, and pectorals, and similar cases are not very uncommon, especially after serious dislocations of the humerus.

210. **The deltoid.**—Paralysis of this muscle from blows upon the shoulder or dislocation of the shoulder-joint is one of the most common forms of paralysis in the upper extremity.

The circumflex nerve is exposed to injury in its course

through the muscle, and its trunk may also be strained in dislocations, or it may be compressed by a crutch or axillary pad. The teres minor suffers with the deltoid when the injury is to the trunk of the nerve; when the injury is in the intra-muscular part it may escape. It

FIG. 77.—Paralysis of right deltoid.

is not always easy to determine the state of the teres minor by electrical testing, as it is so much covered by other muscles, nor by observing the voluntary movements of the patient, as its functions can be adequately performed by the infra-spinatus. The attempt

to ascertain its condition, however, should always be made.

The spinati are often paralysed by the injury which paralyses the deltoid.

The flattened appearance of the shoulder, and the prominence of the acromial process of the scapula make it easy to recognise paralysis of the deltoid, unless the subject be very stout. In infants also the adipose tissue which covers the shoulder may mask the wasting of the muscle. When the wasting and paralysis are extreme the head of the humerus is no longer held up in the glenoid cavity, but can be seen and felt to hang loosely in a state of partial dislocation, and to be freely moveable in its socket. One may even be able to push the tip of a finger between the acromion and the head of the humerus. In cases of paralysis of the deltoid it is not uncommon to find some adhesions or creaking in the shoulder joint; for an injury of the circumflex nerve may produce paralysis of the muscle and changes in the articular surfaces. In examining a patient who complains of weakness in the shoulder it is useful to bear this in mind, and to test the condition of the deltoid, for otherwise one may regard the case as one of primary arthritis of the joint when the articular mischief is in reality secondary to injury or disease of the circumflex nerve.

When the deltoid is paralysed the arm cannot be raised to the horizontal position, and the utility of the limb is very seriously diminished for a very large number of movements, as there is no other muscle able to supplement it to any appreciable extent; the supraspinatus has a similar function to the deltoid, but it is too feeble to be able to raise the weight of the arm. It sometimes happens that part only of the deltoid is para-

lysed; I have notes of three cases. In one the patient had had suppuration round the shoulder, and an incision for the evacuation of the pus was made on the posterior aspect of the joint. One of the branches of the circumflex nerve was injured, and the posterior half of the muscle was wasted, and showed a partial reaction of degeneration. Under electrical treatment combined with daily rubbing the muscle recovered.

The deltoid is rather apt to suffer in infantile paralysis of the upper limb, and the chances of its recovery in this disease are not good. I have known a paralysis of this muscle persist as the remnant of an extensive paralysis of the whole upper limb, and in other cases have found it most difficult to recognise any new growth of muscle-fibres in the deltoid, even after months of persevering electrical treatment. This may mean that the nucleus of origin of the fibres which supply the deltoid is a small circumscribed one, or that the muscle, working as it does at great mechanical disadvantage, cannot afford the loss even of a portion of its fibres without serious impairment of its powers.

In one of my infantile cases the posterior third of the deltoid has grown again under treatment into a fairly strong muscular bundle, the rest of the muscle remaining quite wasted.

In the ordinary traumatic paralysis of the deltoid the prognosis is more favourable. The majority of the cases recover, but there is a considerable minority which do not, and on this account it is wise to express a guarded opinion when there is much wasting and a reaction of degeneration, and the prognosis must be made to depend upon the behaviour of the muscle under treatment. If the electrical reactions are normal, or show only a quantitative change, or the partial reaction

of degeneration, the prognosis is more favourable. Taken generally, the deltoid may be said to be a muscle which is easily damaged, and has not a very great recuperative power. The presence of articular changes in a case of paralysis of the deltoid is very common, as both muscle and joint are supplied by the circumflex nerve, and both suffer when the nerve is injured. Adhesions in the joint should be treated by mechanical means after the nerve has recovered its functions. If the adhesions are broken down before the muscle and nerve are restored they are very likely to form afresh. The skin over the deltoid receives sensory fibres from the circumflex nerve, and impairment of sensation or anæsthesia is frequently to be found if looked for when the muscle is paralysed.

211. **Combined paralyses of the upper limb.**—It often happens that many of the muscles of the arm are paralysed together from injury or disease of the nerve-trunks. Inflammatory processes or syphilitic or other new growths may affect some of the nerve roots at their points of exit from the vertebral column in the the neck. After a serious dislocation of the shoulder, and particularly if this has remained for some hours unreduced, there may be complete paralysis of the whole limb. Mr. Bowlby has published* several cases in which rupture of all the roots of the brachial plexus has been caused by violent injuries or dislocations of the shoulder. When the roots are torn out of the spinal cord there may be laceration of the fibres destined to emerge from the thoracic cord to supply the cervical sympathetic, and the pupil on the injured side may be contracted in consequence. Several cases have been reported in which this has been observed.

* "Injuries and Diseases of Nerves." London, 1889. J. & A. Churchill.

Several causes combine to produce extensive paralysis after a dislocation. The head of the humerus presses upon the brachial plexus in dislocations forward below the coracoid process, and so produces paralysis below that point; but this pressure will not cause paralysis of the muscles of the scapula, for these are supplied by branches given off higher up, and yet they are generally, if not always, implicated. It is said that the upper cords of the plexus may be compressed between the clavicle and the vertebral column if the violence has tended to drive the shoulder backwards, for the shoulder has free play from the sterno-clavicular joint, and might be driven sufficiently far back to produce such compression. Also the upper cords of the plexus are directly subjected to traction from the injury, or finally they may be damaged by the efforts employed in reducing the dislocation, and from their position and direction they are more likely than the lower roots of the plexus to suffer in this way.

It seems probable that the upper cords of the plexus are most likely to be injured by traction, either in the injury or in the efforts to reduce the dislocation; while the nerve-trunks of the arm are injured lower down by the pressure of the head of the bone against them. The subscapular nerves by their position, and by the direction in which they run, are rather better protected than the other nerves from both these accidents; and this perhaps accounts for the frequent escape of the latissimus dorsi, the subscapularis, and the teres major muscles in extensive paralysis of the shoulder and arm from injury. These muscles may also escape complete paralysis after injury through deriving their nerve supply from many separate nerve-roots of the brachial plexus.

212. **Erb's paralysis.**—One particular type of combined paralysis affecting the muscles of the shoulder and arm has received this name, though in France it is often known as the Duchenne-Erb type, because Duchenne first drew attention to it, and reported five examples. It was Erb who, in 1874, pointed out the anatomical reasons for the special grouping of the paralysed parts. The affected muscles are the biceps, coraco-brachialis, and brachialis anticus, which are supplied by the musculo-cutaneous nerve; the deltoid (circumflex nerve), and one muscle supplied by the musculo-spiral, namely, the supinator longus; often the spinati too (supra-scapular nerve) are involved. The affection of the supinator longus alone among the muscles supplied by the musculo-spiral nerve seems at first to be a perplexing feature, but it is easily explained on the ground that the injury is situated above the point at which the musculo-spiral nerve is built up. Compare the condition in wrist drop from lead, in which the supinator longus may escape when the rest of the musculo-spiral area is affected. Erb pointed out that an injury limited to the two upper roots of the brachial plexus, the fifth and sixth cervical, or their combined trunk, would produce the kind of paralysis under consideration; and further showed that these cords can be directly stimulated at a point in the neck one inch above the clavicle and a little external to the outer border of the sterno-mastoid. This is known as Erb's motor point, and by means of an electrode applied to it the muscles in question can be readily thrown into simultaneous contraction (§ 131).

The existence of Erb's paralysis as a clinical unit depends upon the comparatively exposed position of these two nerve roots, just as we have seen that para-

lyses of some of the single muscles of the shoulder are common for the same reason, and varieties in the extent of the paralysis exist according as the injury or disease affects chiefly the fifth or the sixth roots or their united trunk.

From the investigations of Ferrier, Herringham (§ 132) and others, we have a fair knowledge of the levels at which the different components of the nerves of the upper limb leave the spinal cord. There is a certain amount of variation between individual cases, so that we cannot state absolutely that certain fibres run always in the fifth root, and certain others only in the sixth or seventh. Moreover many, or most of the limb muscles, receive their nerve-supply by roots emerging at more than one level; for example, the serratus magnus from the fifth, sixth, and seventh cervical roots.

From what is known one would expect that a lesion of the fifth and sixth roots, or of their combined trunk, should involve not only the muscles already mentioned, but also the rhomboids, the teres minor, the subclavius, and the upper parts of the pectoralis major and serratus magnus, and the supinator brevis, and most of these muscles have been noted as involved in some of the recorded cases. When they escape it must be due to their extensive representation in the nerve-roots which go to make up the brachial plexus.*

It must be borne in mind that Erb's paralysis is not in the least a special form of disease. The name has the advantage of brevity alone. Any sort of injury or disease which is limited to the upper part of the brachial plexus will produce paralysis of the group of shoulder

* For much important work upon these and associated matters, see Sherrington, "The Spinal Animal," *Med. Chir. Trans.*, 1899.

and arm muscles already mentioned. In particular, injury to the child arising during difficult labour is a common cause, so that Duchenne described it as "obstetrical" palsy of the arm. Among twenty cases of which I have notes, seven were caused in this way, four

FIG. 78.—Paralysis of trapezius, spinati and deltoid on right side.

followed direct injury, one was due to sarcoma of the cervical vertebræ, though, from extension of the disease, the paralysis was not long limited to the muscles of the Duchenne-Erb group. One was associated with an abscess in the neck, and the remainder came on gradually and were due to neuritis of some kind.

All degrees of combined paralysis from the typical Duchenne-Erb type to complete paralysis of the shoulder and arm may be met with.

The triceps in some cases and the extensors of the wrist in others, have been noted to be weak in cases of Erb's paralysis. In two cases I have noted some weakness of the upper part of the pectoralis major.

Infantile paralysis may sometimes resemble Erb's paralysis in its distribution, but it is not likely often to be confounded with it if the history of the case and the distribution of the paralysis be carefully taken into account. Fig. 77 is from a case of infantile paralysis, and shows wasting of the deltoid, spinati, and trapezius, the last only in its upper part.

213. **The nerve-trunks of the arm and forearm.**—The musculo-spiral, the median and the ulnar nerves are often injured in their course in the arm and forearm. The usual causes are pressure, including pressure from bandages or splints too tightly applied, incised wounds, implication in callus or scar tissue, and contusions. Pressure palsies affect more especially the musculo-spiral in the upper arm; while the ulnar and median suffer more particularly from incised wounds, and in the forearm. In all cases the first thing to do is to test to determine the situation of the lesion, its severity and above all, to ascertain whether the nerve is likely to be severed or not. If it is severed treatment by electricity is useless until it has been sutured (see § 140). Paralysis from the pressure of splints and bandages is sufficiently common to be of importance, and though fortunately it is not usual for injury produced in this way to cause permanent harm, yet sometimes it does do so. I have notes of a case in which the ulnar muscles were almost totally atrophied as the

result of bandaging, and I have seen quite a considerable number of cases in which there was little or no doubt that the bandaging had been the cause of paralysis. Thus in one patient who received an incised wound involving the median and ulnar trunks it was found, when the wound had healed, that he had developed a paralysis of the musculo-spiral as well. I have little doubt that many of the cases of so-called "reflex paralysis" have been due to injuries from splints and bandages. Paralysis from tight bandaging is seen with especial frequency among persons who have received injuries when far away from skilled assistance, and have been bound up tightly and left so until medical assistance could be reached.

In all cases of injury to nerves, except when the nerve is severed, electricity is by far the best mode of treatment. Arm-bath methods are of great convenience for injuries at or below the elbow, but good results are also obtained by direct applications. The coil or sinusoidal current may always be used, and in cases with RD it may be supplemented by the battery current applied in a labile manner.

214. **The musculo-spiral nerve.**—Paralysis of the muscles supplied by this nerve is characterised by the presence of wrist-drop; usually the extensors of the wrist and fingers and the supinator longus and brevis are involved; the triceps may either escape or may be involved according as the injury is high up in the arm or not.

Musculo-spiral paralysis from pressure on the trunk of the nerve during sleep is extremely common, at least among hospital patients.

The usual history is that the patient having had too much to drink goes off into a heavy sleep, from which

he awakes with his hand and forearm powerless. Often the patient has slept while sitting at a table with the head resting on the arm, or with the arm hanging over the back of a chair; in either case the musculo-spiral nerve trunk has been pressed upon. Almost always the patient has been under the influence of alcohol and has slept very soundly. Otherwise the discomfort felt in the arm would have been likely to awake him before the production of more than a transient paralysis. Almost all the cases are in intemperate persons. The predisposing effect of intemperance is well shown in the following case:—A potman after sleeping for two or three hours developed a pressure palsy of his left musculo-spiral nerve. This got better, but in the following year he injured his ankle and was obliged to use a crutch. This brought on another attack of musculo-spiral palsy before he had used the crutch more than ten days.

Slight degrees of temporary paralysis from pressure on a nerve-trunk during sleep are familiar to most persons. To notice a numbness or a feeling of pins and needles in one arm on awakening from sleep is not uncommon, especially among those who are not in vigorous health.

Pressure paralysis has been thought to be secondary to compression of the blood-vessels of the limb, producing anæmia of the nerve, but if this were the case the paralysis should not be confined to the region of one particular nerve-trunk, as is the rule. It would rather be expected to involve chiefly the distal parts, irrespective of the nerve supply if it were due simply to anæmia of the limb from compression of the main artery.

A case which came under my observation some years ago of a pressure palsy in the leg shows that it is the

nerve itself which suffers from compression. In that case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery. The patient was a young man who attended a meeting, and in order to have a better view of the proceedings he sat for an hour upon the back rail of his chair; at the close of the meeting he found his leg numb and helpless, and was assisted home. Two days later he came under observation. He had paralysis of all the muscles below the knee. He recovered in a fortnight under treatment by rubbing and the induction coil current.

Sleep palsies are almost always limited to the musculo-spiral nerve.

In crutch palsy too it is usually the musculo-spiral nerve alone which is paralysed, but the circumflex nerve, or the ulnar or median may also be involved. Sleep palsies are always unilateral; crutch palsies may be double if two crutches are used, they are usually more marked on the side of the injured leg.

The degree of impairment of sensation varies much; as a rule there is some complaint of numbness on the back of the forearm and hand, and some anæsthesia may be detected.

Pressure palsies vary considerably in severity. Those in which the electrical reactions are not much impaired may recover in ten days or a fortnight. When the reaction of degeneration is present the duration will be longer. Recovery can be confidently expected in uncomplicated cases, where the pressure has not lasted very long, and it is certainly promoted by electrical treatment. I have often seen improvement start at once on the commencement of electrical treatment, after weeks had been wasted in vain in the expectation

of spontaneous recovery. It is probable, however, that even in these the paralysis would go away of itself in time, but this does not prove that electrical treatment is unnecessary.

When the pressure is due to the use of crutches they must either be given up, or if that is impossible the head of the crutch must be well padded, and the state of affairs must be explained to the patient so that he may be able to co-operate; crutches with handles which can be grasped in the hands are the best, for with them the patient can transfer part of his weight from the armpits to the wrists.

The other common affection of the musculo-spiral nerve, namely, lead poisoning, has been dealt with in a preceding paragraph. Implication of the nerve in callus after fracture of the humerus is not very rare and may require a surgical operation to liberate it. The nerve may also be wounded by the fragments of the bone in cases of fracture.

215. **The ulnar and median nerves.**—These nerves are frequently divided at or near the wrist by incised wounds; a very large number of the cases being from cuts caused by broken glass. It is not uncommon for both nerves to be divided in one accident, and if the ends are not re-united when the wound is first dressed, wasting and paralysis of the intrinsic muscles of the hand is the result.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are:—1. Paralysis with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The palm

becomes thin and flat, the heads of the metacarpal bones become unduly prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. It has already been shown (§ 190) that in the foot the action of the long flexors of the toes is to flex the distal phalanges only, and that of the long extensors is to extend the proximal phalanges, and that when the interossei are paralysed the clawed attitude of the toes is produced in consequence. The mechanism is the same in the case of the hand, the interossei flex the proximal phalanges and extend the distal ones ; and so supplement the movements of the fingers which are performed by the long flexors and extensors. 2. There is loss of sensation in the little finger, in the ulnar half of the ring finger both front and back, and in the corresponding part of the palm and the dorsum of the hand. 3. Trophic changes are sometimes produced in the skin and finger nails of the anæsthetic area, often with œdema ; the temperature of the part is lowered, and sometimes there is very severe pain of a burning character, to which the name of "causalgia" has been given, this is not very common, nor is it usually present when the nerve has been completely divided. When it exists the temperature is raised above that of the opposite side, and the patient experiences a sensation of heat and seeks for relief by cold applications. These trophic changes signify an irritative lesion, and are not found from simple division of the nerve-trunk.

After division of the median nerve at the wrist the conditions are different, the clawed hand which is so characteristic of the divided ulnar nerve is not present, and the chief feature is the wasting of the thenar eminence, and the averted or ape-like thumb, which lies

with the nail facing dorsally; the abductor, opponens and outer head of the flexor brevis of the thumb are paralysed, atrophied, and show the reaction of degeneration. There is loss of sensation in the thumb, index, middle, and half the ring fingers, and in the corresponding part of the palm, and of the two distal phalanges of the same fingers on the dorsum of the hand.

216. **The lower limb.**—Paralysis from injury is much less common in the leg than in the arm. I have notes of only a few instances. In one recorded case there was paralysis of the front leg muscles from the pressure of a leather pad upon the peroneal nerve just below the head of the fibula. The patient was a man who walked daily upon stilts which were strapped to the legs, and so set up the pressure upon the nerve. Another case is referred to in § 214.

Other cases have followed injury about the knee-joint, or a fracture through the lower third of the femur, and one was after an operation for the relief of genu valgum. The most usual seat of the injury to the nerve-trunks of the lower extremity is in the external popliteal nerve or the peroneal nerve. This was the case in two instances which have come under my notice. The pressure occurred during work. In one, a carpenter sat on the ground with one leg doubled under him, in the other, a leather sewer fixed her work against the under side of a table, holding it there by the upward pressure of the left knee against the outer side of the right knee which was crossed over the left one. In both cases there was pressure upon the peroneal nerve.

217. **Muscular atrophies.**—Prolonged treatment by the sinusoidal bath method has been applied to several cases of the shoulder and upper arm type (Landouzy-Déjérine) of muscular atrophy in the elec-

trical department at St. Bartholomew's Hospital without any decided result. The most that could be said of the cases was that there seemed to be some retardation of the advance of the muscular atrophy while treatment was in progress. In other cases with the peroneal type (Charcot-Marie) of muscular atrophy the results have been equally unfavourable.

218. **Pes cavus.**—This has already been noticed under the heading of infantile paralysis. It is often present in diseases which lead to muscular atrophy, and then signifies a paralysis of the interosseal muscles. But in many cases of pes cavus the electrical reactions of the interossei are not altered and the deformity is due to spasm of the long flexors and long extensors rather than to weakness of the intrinsics of the foot. Cases of this kind are not uncommon and are seen in young adults, with a history of gradual onset. Both sides are involved. The knee jerks are excessive and the leg muscles are large and firm, the interossei give normal reactions in these cases which are clearly spinal in character and correspond best to the descriptions of primary lateral sclerosis. In these cases electrical applications do no good but rather the opposite.

219. **Neuralgia. Painful neuritis.**—The word neuralgia is applied to many different conditions in in which pain is felt in the course or area of distribution of a nerve, and the term has been defined as pain in the region of a nerve unconnected with inflammation or other morbid state in the nerve to which the pain is referred. There is no doubt that a neuralgic pain in one part may be set up in a reflex way by irritation acting upon some more or less remote part. Fagge has given as an instance the trigeminal neuralgia so often excited by disease of a tooth, and severe supra-orbital

pain may be instantly produced in some persons by the eating of an ice. Neuralgia of the testis from renal calculus is another familiar instance of reflex neuralgia.

When we compare sensory with motor nerves we find an analogy between anæsthesia and paralysis, and also between neuralgia and muscular spasm. The two latter are especially associated with irritation, direct or reflex, of sensory or motor nerves or nerve centres. And we may also learn from the comparison of motor and sensory phenomena that just as in the case of paralysis the lesion producing it may be in the motor fibres or the ganglion cells, or in the motor tracts of the spinal cord or brain, so too in the case of sensory disturbances the lesion producing them may occupy any part of the sensory tract, peripheral or central, and it is therefore necessary before arriving at any final opinion as to the cause of a neuralgic pain, to explore all those parts so far as is possible. It is folly to regard them all as "neuralgia" and then blindly to apply remedies for neuralgia with hopes of cure when the trouble may be due to any one of a number of causes, some curable others not curable.

It is useful to distinguish between pains referred to the area of distribution of a sensory nerve and pains felt in the course of the nerve-trunk. The former are more particularly associated with the sensory fibres proper, and the latter with the *nervi nervorum* which supply the perineurium of the nerve-trunks with sensibility. It is of especial importance to examine carefully, in all cases of neuralgic pain, for the possible existence of pressure or deep seated inflammation as a cause of the pain. Thus a brachial neuralgia may be due to gumma or other new growth of the cervical

vertebræ, and sciatica to inflammatory processes in the pelvis.

The electrical treatment of neuralgia may take either of two different directions. In the more rational one the action of the constant current is brought to bear upon the seat of pain in the hope that its sedative effects may gradually produce a permanent impression upon the nerve. In the other the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diversion, as it were, in the nature of the impulses conducted along the nerve, and so by influencing the centres to remove the neuralgic condition. Counter-irritation is a very popular treatment for neuralgic pains, and electricity affords a counter-irritant of great convenience in application. Electrical counter-irritation has the great advantage that it does not damage or destroy the skin in the way that blisters or the cautery do. The treatment by counter-irritation is the cruder method of the two, and may do harm instead of good.

When painful points are present in a case of neuralgia the electrode should be applied to them. These painful points correspond to spots at which the cutaneous nerves emerge from bony canals or fasciæ, but perhaps they merely signify a general tenderness of the nerve-trunk, which is most manifested at those particular places where they are most subject to pressure.

220. **Facial neuralgia.**—The fifth nerve is one of the commonest seats of neuralgia, and in very many cases its condition is one of "reflex neuralgia," the teeth in particular being very commonly at fault, while errors of refraction should also be looked for. But not all cases of trigeminal neuralgia can be traced to an exciting cause, and the most severe form, known as *tic*

douloureux, is often present when no source of irritation can be found. The belief that this form of neuralgia is of central origin has much in its favour. Duchenne's treatment for all forms of neuralgia (except those in which some gross lesion of the nerve was present) consisted in severe induction coil applications to the painful area, using a coil of many turns with the wire brush after drying and powdering the skin to diminish its power of conduction. If the skin were not first dried the current penetrating the tissues to the trunk of the nerve was likely to do harm instead of good. He reports one or two cases of severe trigeminal neuralgia which derived benefit from this mode of cutaneous counter-irritation, but confesses that his successes were rare. Statical treatment by the brush discharge (§ 102) will sometimes effect a cure. Daily applications have been advised, and in very acute attacks two or three applications may be made in one day. Tic douloureux will sometimes disappear by simple positive charging.

The stabile action of the anode to the painful part is often of use in trigeminal neuralgia, and this is the method which should be employed in the first instance. It is remarkable to see how a recent neuralgic pain will sometimes fade away quickly under this treatment. Old standing neuralgias are much less easily got rid of, but the same mode of treatment should be applied and persevered in, Bergonié (*Arch. d'élect. médicale*, Oct., 1897) has reported the successful treatment of old standing *tic douloureux* by means of the battery current with large pads to cover the whole side of the face, and large currents. Six cases are given, and a figure of the large pads to be used. The paper is followed by others giving the experiences of Guilloz, Bordier, and

Débédat on the same subject (see also same Journal, June, 1898).

221. **Cervical neuralgia.**—In a patient, a young married women, who had had herpes of the descending branches of the cervical plexus, a persistent neuralgic state of those nerves was left which caused much suffering, and a good deal of anxiety because its nature was not understood. After it had lasted without improvement for nearly two years she came under electrical treatment, and was completely relieved within a fortnight. The localisation of the pain in the nerve-trunks and in their peripheral branches was clear in this case, and applications of the anode were used. There has been no return of the pain since.

222. **Brachial neuralgia.**—Neuralgia affecting the upper arm is not uncommon, and great relief may be given by electrical applications. We may distinguish between deltoid rheumatism which is a neuritis of the circumflex nerve, and a more extensive neuralgic condition of the shoulder, which extends into the arm and sometimes into the forearm and hand, and is probably, in most cases due to a neuritis involving a greater or lesser part of the brachial plexus. The pain may be very severe with exacerbations at times. One severe case in my experience was so bad that the patient could not sleep at night, and a touch in the axilla was enough to induce violent shooting pains which were felt down into the fingers. When the case came under treatment it had already lasted several weeks in spite of all kinds of drug treatment, relief followed quickly upon labile applications of the battery current. Gout, rheumatism, syphilis may be the predisposing causes and should be enquired for and treated. The battery current carefully applied, labile, without interruptions, gives great relief, and if

persevered in will cause the complete disappearance of the trouble. The active electrode must be applied over the seats of most pain, the indifferent electrode to the cervical spine. In some cases of brachial neuralgia of old standing the effect of electrical applications is rapid and complete. A lady who had consulted many physicians without relief was referred to me for electrical treatment some time ago and was treated with sinusoidal baths. She at once began to improve, and within a fortnight was completely and permanently freed from her pains. The cases in which an immediate cure follows electrical applications are perhaps those in which neuralgia persists as a habit after the disappearance of the lesion in the nerve which originally started the neuralgia. I have notes of rapid good results in brachial neuralgias after various kinds of electrical applications, namely the direct battery current applied locally, the sinusoidal arm-bath or general bath, and the statical breeze.

The cases due to neuritis which occur in the gouty or rheumatic and those complicated by the presence of the climacteric period (§ 203) though more slow to disappear, are nevertheless extremely favourable cases for electrical treatment. As has been mentioned already one must always examine one's cases most carefully for possible new growth, inflammatory or other, or for conditions leading to pressure upon nerve-trunks before undertaking the relief of neuralgic pains by electrical applications. Neuralgia following herpes is well known to be more obstinate in elderly patients than in those who are young.

223. **Sciatica.**—Sciatica varies much in severity, and in duration. It is now generally recognised that electrical treatment is useful for its relief, although from

time to time cases are met with where sciatica persists for a long time in spite of treatment, yet as a rule they do very well. The battery current is the best application in recent and acute cases, but general electrification with the bath, using the induction coil or better still the sinusoidal current from the mains, answers well in many of the cases.

Steavenson* has published an account of sixty cases of sciatica treated by electrical applications; of this number thirty-seven were cured, eleven were improved, two failed, and the remainder were uncertain. The method employed was to apply the kathode labile to the back of the thigh along the course of the sciatic nerve, and over the lower portion of the spine, while the anode was placed on the abdomen. The anode may also be placed on the lumbar spine. Each application lasted for eight to ten minutes, and the integument over which the electrode has passed becomes suffused with a bright blush, the patient experiencing a glowing feeling of warmth in the same tract. The stiffness of the muscles is also relieved, and the patient is able to bend down and get up from a sitting position with great ease for several hours, even after the early applications. In the electrical treatment of neuralgic pains large electrodes and large currents should be used. Prognosis is good if the first treatment produce even a temporary relief from the pain.

Counter irritation by means of the wire brush, using the long secondary coil after drying the skin and powdering it with starch powder, is sometimes efficacious in old cases of sciatica, as in other forms of neuralgic pain; the battery current, however, is a much better treatment in bad cases. Descending currents stabile,

* *Lancet*, Jan., 1884, and July, 1886.

with a few interruptions (not reversals) to close the sitting are preferred by Remak, and most later authors. My own practice is to begin with the battery current, following Dr. Steavenson's rules, and after a time, when the severity of the pain is subsiding, to employ the electric bath with sinusoidal current. This mode of application is useful as soon as the patient finds it comforting, and until this is the case the battery current must be used in preference. Old standing cases of a subacute character may be treated by the sinusoidal current immediately.

224. **Other forms of neuralgia.**—Painful affections of other nerves, for example the anterior crural nerve, are sometimes met with, and may be treated in an analogous manner. Relief almost always follows, though it may be slow in coming. Electrical applications should never be neglected in cases of neuralgic pain, for they are far superior to the treatment by drugs and irritant applications which have been in vogue for so long a time.

Steavenson and others have described a neuralgic state of the pudic nerve.* The affection is associated with severe pains in the perineum, often periodic, and increased by walking; it is sometimes accompanied by a painful spasm of the urethra whenever an attempt is made to pass water. The pain sometimes extends beyond the perineum into the groin. The constant current applied locally will generally relieve the pain after a few applications.

225. **Anæsthesia.**—The treatment of anæsthesia is similar to that used for paralysis (§ 189). The cerebral anæsthesia which sometimes occurs with hemiplegia is usually not permanent, and it may very often be made

* *Lancet*, 1886, vol. ii., p. 181.

to disappear by a few applications of the wire brush to the affected areas. Hysterical anæsthesia may also be dispelled in the same way as a rule.

When paralysis and anæsthesia coexist from disease of the spinal cord or spinal nerves, the prognosis and the treatment are similar for both. Very often the anæsthesia is much less marked than the paralysis, and it recovers more quickly in the favourable cases.

Anæsthesia of the sensory portions of the trigeminus has also been observed. Fagge quotes from Romberg a case which came on after exposure to cold and might therefore be of a similar nature to the cases of facial paralysis produced in the same way. Serious disease in the neighbourhood of the Gasserian ganglion may also produce anæsthesia of the face.

226. **Optic neuritis and atrophy.**—The battery current has been used for optic atrophy and optic neuritis, and several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is (1) transverse currents through the temples with reversals; (2) longitudinal currents through the head, with the anode over the closed eyelids.

The prospects of improvement depend much upon the nature of the disease; when this is of a progressive kind, as in tabetic atrophy, good results can hardly be looked for. Capriati* recommends a trial, however, and considers that he has obtained improvement with battery currents of two milliampères applied longitudinally to the skull. His views have been summarised as follows:—Electrical treatment is indicated in tabetic

* *Riforma medica*, October, 1893. Abstract in Weekly Epitome of *British Medical Journal*.

atrophy of the optic nerve, in cases in which the disease is not running a very rapid course, and before it has reached a very advanced stage. If employed in the early stages it appears to do good, and arrests, with certain limitations, the morbid process, apparently by acting on the nerve fibres still unaffected. Better results may be anticipated from the application of the current antero-posteriorly than transversely, although neither method has yielded results warranting great enthusiasm. In neuritis affecting the nerves of special sense we usually have to deal with a progressive and degenerative state and on this account treatment cannot give results like those which may be expected to follow simple traumatic lesions of the ordinary mixed nerves.

227. **Auditory nerve deafness.**—The treatment of nerve deafness by electricity sometimes gives good results. The method best suited is with the bifurcated electrode (fig. 69) and the battery current, using the negative pole and interruptions. The current should be turned on and off gradually, and should not exceed ten milliampères, and should be reduced to five before making the interruptions. Even with this strength the patient must be watched for signs of faintness, as syncope may even be produced. Sittings of six to eight minutes, with ten to twenty interrruptions, are best. Under this treatment many patients will have the hearing improved, I have seen a remarkable increase of hearing power follow even the first applications, and the effect may be permanently good. The causes of nervous deafness of course are numerous, and the cases should be chosen; only those which from their history and the results of electrical testing appear to be favourable should be undertaken. The best results follow on prolonged courses of daily treatment, and intelligent

patients can be taught how to carry out treatment for themselves and should be encouraged to persevere for one or two months.

228. **Tinnitus aurium.**—Subjective noises in the ears can sometimes be dispelled by the battery current. From what has been already said in § 145, it appears that when the tinnitus is associated with an irritable state of the auditory nerve, good results may be expected from the sedative action of the anode, which may be applied by a small electrode to the skin immediately in front of the tragus. I have treated a very large number of patients for this symptom, using as the active electrode (anode) the instrument figured on page 259, which is applied in front of the tragus (or on the mastoid processes) of both ears at once. The parts in contact with the skin should not be of less diameter than two centimetres. If the surface of the electrode is too small some soreness of the skin may be produced at the points of contact. A pad of moist absorbent wool should be placed between the electrode and the skin. The indifferent electrode is placed at the back of the neck, where it is kept in position by the pressure of the clothing; and a galvanometer and a rheostat (fig. 48) should be included in the circuit to enable the operator to introduce or remove a resistance of 10,000 ohms quite gradually. When everything is ready the current is slowly and steadily raised by the current collector to five milliampères (the rheostat being at zero) and allowed to pass for ten minutes. As the resistance of the skin diminishes the current will increase slowly, the galvanometer may be allowed to indicate eight or ten milliampères, each ear is then receiving half that current. If the current should be inclined to rise higher the rheostat must be brought into use to keep it at that

strength. The patient should be instructed to pay attention to the noises and to give notice of any change occurring in them in the course of the sitting. The effect of the application of the anode to the ears is to diminish the noises, while that of the kathode is to increase them. The reverse sometimes happens, however, and therefore the patient must be tested to find out whether the current modifies the sounds. If it does so the prospects of improvement are good, and the patient should be encouraged to persevere. If neither anode nor kathode alter the sounds, the prognosis is unfavourable, and it is hardly worth while to continue the treatment. In favourable cases the noises will diminish during the passage of the current; if the current be too quickly reduced at the end of the treatment the noises may return as loudly as before, but if it be reduced very slowly and gradually this does not happen. On this account the rheostat is an important part of the apparatus; at the end of the sitting the current is to be reduced by the rheostat first and afterwards by the collector. If it happens that the tinnitus is dispelled by the treatment, at first the relief is quite temporary and the noises will probably return within an hour, but after each sitting the period of quiet is longer until finally they disappear altogether. If the sittings are repeated daily for the first week much time will be gained, afterwards it will be sufficient to apply the treatment twice a week for a fortnight or three weeks, or a month, according to the progress of the case.

Tinnitus complicates nearly all the different forms of ear disease, for instance it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, which can easily be cured

by proper local treatment, or it may occur in patients whose auditory apparatus is normal, as a part of some general morbid condition.

More commonly, however, some chronic ear mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness or other troubles.

Electrical treatment is able to do a very great deal for some cases provided it be properly managed.

It has been objected to the electrical treatment that it is difficult and that the results are uncertain and temporary, but there is no doubt whatever that in a fair proportion of cases some relief follows, while some patients are quite freed from their tinnitus and deafness. It is not impossible that the treatment has an effect upon the sclerotic change itself (see §§ 229, 230) and in addition it certainly has an effect upon the auditory nerve fibres tending to improve their nutrition. But unhappily in many instances of tinnitus aurium and deafness we have to deal with a progressive degenerative disease and we do not know how to apply electricity to arrest this tendency.

CHAPTER XIII.

Other Conditions requiring Electrical Treatment.

The relief of congestion. Joint affections. Inflammatory exudations. Ascites. Corneal opacities. The urinary organs. Nocturnal incontinence. Constipation. Sexual disorders. Cutaneous affections. Galactagogue effects. Guinea worm. Suspended animation. Electricity as a test of death.

229. **Joint affections.**—The influence of electrical applications in relieving joint affections was investigated by Remak* so long ago as 1856. As has been already observed, the special study of the uses of electricity for paralytic affections has tended to divert attention from many of its other applications, among which its uses in the relief of congestion and in promoting absorption occupy an important place. Remak's cases are so well described as to leave no doubt that in his hands much benefit was afforded both in acute and chronic joint affections. He employed the continuous current exclusively, and, so far as one can judge, currents of fairly large magnitude. Among the cases which he has reported are several of sprains and injuries of joints, and of chronic arthritis of rheumatic and other kinds.

As an example of the effect of the battery current in relieving severe congestion, the following case, reported by Remak, seems to be worthy of being reproduced in abstract.

A washer-woman, aged 36, fell from a table and felt her right foot to be twisted outwards; so much pain

* "Galvanotherapie." R. Remak, 1860.

was produced that she could not walk. During the rest of the day and through the night she applied cold water dressings. The following day she consulted Remak; she was obliged to drive to his house, and ascended the stairs with great pain and difficulty. He found the dorsum of the foot much swelled, livid and very tender; the diagnosis made was laceration of some of the tarsal ligaments, and extravasation of blood. The aspect of the foot was such as to lead to the apprehension that gangrene might result. At the patient's urgent request electrical treatment was applied. Owing to the thickness of the skin of the sole of her foot it was necessary to use a large number of cells in order to produce any sensation or reddening of the skin. By repeatedly changing the place of application of the electrodes he continued the application for twenty-five minutes. During this time the livid colouration disappeared, the œdema and the pain diminished considerably, and the patient could rest her heel upon the ground better than before. The warmth of the foot, increased by the current, continued until the evening, by which time a decided improvement was established, and she passed a good night without pain. Next day the colour of the foot was normal, and the symptoms were less severe; the treatment was repeated on this and on the next three days. She was then so much better as to walk without lameness, and in a fortnight was practically well. The mode of application is not clearly stated but it appears probable that the positive pole was applied chiefly to the sole of the foot, but also to the dorsum, while the negative was on some indifferent part higher up the limb or on the trunk. The view taken by Remak in this and in similar cases which he reports is that the current produces a marked increase in the rate

of circulation through the part treated, by a general dilatation of its blood-vessels, and as a consequence of the improvement in the circulation the products of effusion are much more rapidly carried off than would otherwise be the case. This view is reasonable, and is perhaps the only one which is capable of explaining the rapidity of the cure.

There is no doubt that the constant current may be regarded as having a special power of improving the circulation in a part and as being useful in this way in promoting the removal of œdema and products of inflammation, and generally for the treatment of all injuries of joints.

With chronic joint pains of rheumatic origin the local application of the battery current, by means of large pads, proved equally useful in Remak's hands. His best results were in patients who continued to have stiff and painful joints after the rheumatic fever had left them.

He quotes a case where there had been rheumatic fever; the patient was ill for seven weeks in his own house and for ten weeks in hospital. When discharged he was thin and pale, his joints were stiff, especially the knee and ankle joints, round which there was thickening. He was then treated by continuous currents applied to the several affected joints, and after six days of treatment was much more free from pain, had more power, and the thickenings had nearly disappeared.

Muscular spasm round an inflamed joint is also relieved by applications of the anode.

In those cases of chronic joint affections which I have had the opportunity of treating relief has commonly been afforded, sometimes after a brief course of treatment. Chronic rheumatic joint pains will often yield

in a most remarkable manner to electrical applications, even when they have proved most obstinate to other forms of treatment. The best method of applying electricity is by local applications of the negative pole.

In gouty arthritis electrical treatment will hasten the recovery when the acute paroxysm is over. In the case of a hand or foot the part may be immersed in warm water to form a local bath, as described in detail in § 167, which see.

Among recent writings on the subject of the value of electricity in the treatment of stiffened joints, a paper of Professor Leduc (*Arch. d'électricité médicale*, 1894, p. 478) is to be noted, for it gives us the evidence of an exact scientific observer. He describes the case of a young lady who developed phlebitis after typhoid fever. Following upon this there was a stiffening of the left knee joint which was treated unsuccessfully in various ways for more than a year. When seen by Dr. Leduc the joint was ankylosed, immobile, and painful; it felt cold to the touch, and the tissues surrounding the joint were thickened and slightly œdematous. She could not walk nor bear with any weight on the limb. Electrical treatment was commenced. A large electrode (negative) was moulded to fit the region of the joint, the positive indifferent electrode being applied to the epigastrium, and a current of twenty milliampères was applied for ten minutes. Afterwards thirty and forty-five milliampères for fifteen minutes were employed. Improvement quickly began and after twenty-two applications extending over two months the joint had become freely movable and the patient could stand and walk.

Other cases of the same kind are referred to and the writer concludes by saying that the useful action of

electricity in cases of joints stiffened by past inflammation is incontestable. A point of importance for success is that the treatment must only be applied to joints which are no longer the seat of inflammation. It is necessary to wait until all active mischief in the joint has subsided.

In another paper kindly sent to me by Professor Leduc and reprinted from the *Gazette Médicale de Nantes*, January, 1893, seven cases are reported which afford valuable evidence of the advantages to be derived from applications of electricity to joints stiffened by old injury or past inflammation. One, a rheumatic case, in a gentleman aged 47 was such that for two years the patient had to be dressed and carried from his bed to his couch by attendants. He could not stand up. After thirty applications of the battery current during sixty days he could walk well enough to undertake a a journey to Paris, and his improved condition was well maintained. In a conversation with Professor Leduc in 1899 he told me that he still found the treatment of stiffened joints by the battery current to be one of the most satisfactory things in the whole field of medical electricity. He considers the negative pole to be the most effective for the purpose. Large electrodes moulded to fit the surface of the joint are to be used. The current may be very conveniently applied through the medium of a monopolar or other arm bath when the affected joint is either the wrist, the ankle, or the elbow.

230. **Inflammatory exudations—adenitis.**—The continuous current is sometimes of great use for promoting the resolution of other chronic conditions due to inflammation. In enlarged lymphatic glands, Remak and many other writers have mentioned this effect, or reported cases. I have myself had under treatment a

patient with numerous enlarged lymphatic glands of the neck which decreased very notably in size under electrical applications. In the *Archiv. d'élect. médicale*, vol. i., will be found an admirable paper on this subject with reports and summaries of twenty-three cases by Dr. Labat-Labourdette. He recommends the negative pole and considers the method of great value in cases of simple chronic adenitis or in tubercular adenitis in its early stages.

Moritz Meyer* has seen deep cicatrices in muscle soften and disappear, and periostitis from gunshot injuries absorbed with remarkable rapidity. Both effects were procured by the use of the positive pole. Cheron again has seen stiffness of joints and plastic exudation from gunshot wounds removed chiefly by the application of the kathode.

Keloid scars have also frequently been reported to have disappeared under electrical treatment, but it must be borne in mind that they may fade away spontaneously.

231. **Orchitis.**—Scharff (*Centralbl. f. Krankh. d. Harn und Sex. Organe*, 1, 1894) claims to have employed electricity successfully in the treatment of cases of epididymitis. He does not wait until the affection has become chronic, but immediately and during the acute stage applies the anode to the lower part of the scrotum. The patient being in the dorsal position, a large electrode, with a maximum current of half a milliampère is employed, the duration of the application being three minutes on the first occasion; this is afterwards increased to five and ten minutes, the increase being very gradual. The weak constant current thus employed should be carefully gauged with a sufficiently

* Quoted by Erb, "Electrotherapeutics."

sensitive galvanometer, and the current closed insensibly with the aid of a rheostat. No unpleasant sensation should be thus produced, but the patient will subsequently on palpation be able to observe a considerable diminution or total disappearance of the tenderness which had previously existed. While in the same position a suitable suspender is applied, and the patient then allowed to walk about. Towards the seventh day the current can be increased to three milliampères, the same electrode, however, being still used for a few days, when it can be somewhat reduced in size. The kathode is placed above the groin and on the abdominal wall. By this treatment, rest in bed can usually be dispensed with, the other advantages over the older methods being rapid and marked relief of the pain from the first, and greater rapidity in the disappearance of the swelling. Onimus also speaks very favourably of the good effect of electrical treatment in orchitis, and Dr. Picot, of Tours, has reported good results in forty cases; they used currents of about five milliampères.

Dr. Duboc,† of Rouen, has reported two cases of chronic orchitis and epididymitis following gonorrhœa treated successfully by electricity, one had lasted for eighteen months in spite of much medication, the other for nine months. In both cases the swellings disappeared rapidly and completely after about six applications. Two pads were used, one in front of the testicle and one behind; both were moistened with a twenty per cent. solution of iodide of potassium, a battery current of twenty milliampères was used for ten minutes.

232. **In serous effusions.**—Ascites and hydrocele have been treated by electricity and several writers have

† *Arch. d'élect. médicale*, 1894.

reported favourably of the treatment. In ascites the induction coil current applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen, has been followed by increased flow of urine and disappearance of the ascites. The prospects of permanent cure of course depend upon the cause of the ascites in each particular case.

It is probable that battery currents might act even better than coil currents for the relief of this condition, by their greater action upon the vascular system of the abdominal organs.

233. **Corneal opacities.**—Alleman* in a valuable paper on applications of electricity to ophthalmology, gives an account of the treatment of corneal opacities by the continuous current. He says: "That from the observation of a number of cases, extending over a considerable time, he is convinced that the use of electricity promises the only treatment of avail in corneal opacities of long standing." The kathode is applied to the cocainised cornea, and has the form of a silver rod, seven milliampères in diameter, the flat end being used; from one half to four milliampères for one or two minutes are used. He has satisfied himself by strict tests that the results are really good. More care is needed with recent scars than with older ones.

More recently several experimenters in this country have confirmed these observations and have reported their experiences in the *British Medical Journal*. Synechiæ have also been frequently observed to fade and disappear under applications of the battery current through the closed eyelids. Those who are interested

* Bigelow, "System of Electro-therapeutics," F. A. Davis & Co., Philadelphia and London.

in the subject will find a useful paper by Dr. Pansier of Avignon in the *Arch. d'électricité médicale*, 1894, with notes of twenty-four cases.

234. **Cutaneous affections.**—Electrical applications to chronic ulcers of the skin will improve its condition and promote healthy cicatrisation, a layer of moist lint or absorbent wool should be laid over the ulcerated part and the electrode applied to this, or the current may be caused to reach the skin through a locally applied bath. I have seen prompt and permanent healing follow treatment by the interrupted current of an obstinate varicose ulcer of long standing. Patients who are taking a course of electric baths usually lose any acne of the skin of the back from which they may have been suffering at the commencement.

Other observers have noted that obstinate pruritus can often be cured by the brush discharge; and it can also be relieved by other electrical applications.

These facts all show that the nutrition of the skin can be markedly influenced by electrical applications; and the warmth and redness which is produced by electrical treatment of a part is another sign of this direct effect upon the cutaneous circulation. It has long been known that chilblains respond favourably to electrical treatment. Many things point to the probability that electricity will some day occupy an important place in the treatment of skin diseases. The static breeze, the brush discharge from the Tesla coil, and the Röntgen rays all show marked effects upon the skin which can often be turned to good account in treatment.

Dr. Marquant* has reported a series of twenty-three cases of eczema and eczematous ulceration treated by the electrostatic brush discharge with very good results.

* *Arch. d'électricité médicale*, 1894, pp. 329, 385.

His method had previously been tried by Prof. Doumer, who has also published a communication in the same journal.*

The patients were placed on an insulating seat connected to the negative pole of the machine, and the positive pole was connected to a pointed electrode and held close to the affected part. In his concluding remarks, he says that the beneficial effect was superior to that obtained by any other kind of treatment. It was more quickly produced in those patients whose general health was good, than in those who were constitutionally unsound. The local pain, and the congestion and discolouration round the ulcers quickly disappeared, and healthy cicatrisation commenced rapidly. Oudin (§ 110) has reported a number of cases treated successfully by high frequency discharges.

235. **Myalgia.**—This is the name given to those pains which are felt in over-fatigued muscles; when patients are in a condition of debility, the amount of muscular exertion which sets up these myalgic pains may be so small that the connection between them and their true cause may be entirely overlooked. Hence myalgia is constantly confounded with hysteria, rheumatic, spinal, and other diseases.† The symptoms are pain in the muscles, made worse on movement, and tenderness. The skin over the muscles may also be very tender. The pains are often referred to one of the tendinous insertions of the affected muscle, and the trunk muscles are most commonly affected. Dr. Inman mentions as common seats of myalgic pains (1) the trapezius at its insertion into the occipital bone and into the spine of scapula; (2) the spines of the dorsal

* *Idem.*, p. 141.

† Inman on "Myalgia," Churchill, 1860.

and lumbar vertebræ (origins of spinal muscles); (3) the front of the chest (origin of pectoralis major and minor) producing infra-mammary pain; (4) at the margins of the ribs, or at the pubes (insertions of recti abdominis).

Myalgia may exist in persons who are apparently healthy, and it may be difficult to decide what is the particular cause of the muscular fatigue which they suffer from; at the same time their pains may be very obstinate and very troublesome, and may resist all treatment until the diagnosis is clearly established, and rest for the affected muscles can be contrived. The movements which specially aggravate the pain must be carefully ascertained in order to decide upon the exact muscle which is at fault. General or local electrical applications may so improve the tone of the muscles as to enable them to perform without fatigue the work they are called upon to do. Local treatment acts usefully too by improving the circulation in the muscles. The battery current up to 20 milliampères may be used, the anode to the painful parts, the sitting may be terminated by a few reversals. This is the method advised by Erb. Induction coil applications to throw the muscles into contraction and exercise them are also useful.

236. **The urinary organs.**—Incontinence of urine is a symptom for which much can be done by electrical treatment. The cases of this complaint which are met with fall under two distinct groups. In one, there is want of tone in the sphincter of the bladder, and urine is expelled involuntarily during any muscular effort which involves the action of the abdominal muscles; and in the other the muscular apparatus is normal, but the patients suffer from incontinence when asleep.

In women it is extremely common for there to be

some inefficiency of the former kind, and in consequence a little urine is apt to be expelled from the bladder during muscular effort such as lifting a weight or during coughing or sneezing. If the weakness of the sphincter be rather more pronounced the incontinence becomes troublesome and annoying, and advice may be sought. The weakness of the sphincter may also be due to some dilatation or injury of the urethra, for example, during parturition or after a digital examination of the bladder. The tone and power of the female urethra can be strengthened by electrical applications, and the patient's comfort may in this way be greatly increased. I have notes of a patient who suffered from incontinence of this kind, for which she was obliged in the daytime to wear an urinal apparatus, and she was always wet and uncomfortable. A course of electrical treatment completely cured her. In another case, equally successful, the incontinence was the result of an operation upon the urethra for the relief of some painful condition, possibly a caruncle. Since the operation the patient had been unable to hold her water, which escaped during any muscular exertion, so that her condition was most disagreeable to herself. After four or five weeks treatment she was quite well, and able to lift and carry her baby, a strong child a year and half old, without any leakage from the bladder. Other similar cases might be brought forward in which electrical applications have given great relief in this condition. Even when the incontinence is part of a paraplegic condition, treatment applied to the bladder may be of service. I have notes of two women who received injuries to the spine through jumping out of windows. They were referred to me for electrical treatment for their incontinence, and in both the power of the bladder

seemed to be improved by treatment. At the same time they were and had been improving generally before coming under my care, and therefore the results of the electrical treatment they received are not so conclusive.

Another patient who had incontinence as the result of a long railway journey without any opportunity of passing urine was quickly restored to health by electrical treatment.

The treatment of incontinence due to weak sphincter is given in the next paragraph.

237. **Nocturnal incontinence.**—This affection has a totally different pathology to that of the kind of incontinence already discussed. In nocturnal incontinence the patients are quite able to pass or to retain their urine so long as they are awake, but when asleep the bladder is apt to empty itself without awaking them. It is due to a persistence of the infantile condition of micturition. The education of a child includes the education of inhibitory centres which bring the reflex mechanisms of micturition under the influence of the will, so that the action of the bladder is continually controlled. If the control be imperfect the bladder may empty itself whenever the higher centres are in abeyance, as during sleep. A person suffering from nocturnal incontinence may pass water unconsciously in the daytime when asleep in a chair. As a rule sleep is very sound in patients who are the subjects of enuresis nocturna.

Electricity is of use in enuresis nocturna because it is able to stimulate the centres, both cerebral and spinal, by producing painful local impressions which tend in time to bring the inhibitory cerebral mechanism into more close relation with the reflex centres in the lumbar cord. It is important to try to combat the tendency to very

deep sleep which exists in many of these patients. This may be attempted in various ways; for example, the number of the bedclothes should be reduced, so that the patients lie a little chilly at night; and a clock which strikes the hours is also a useful thing to have in the bed-room, especially if the patient can be taught to awake when the clock strikes twelve, or any other hour which may be specified. They must be taught to practise holding the water as long as possible by day, so as to accustom the bladder to become more tolerant of its contents and to train the influence of the inhibitory centres by their exercise.

In children with enuresis nocturna it is important to search for any reflex irritation and to remove it when possible. Thus worms, oxaluria, a narrow meatus, or phimosis, if present, must be dealt with before resorting to electrical treatment.

A very common type of incontinence in female patients is that of nocturnal incontinence complicated by a weak sphincter which causes them to wet themselves by day as well. These cases are obstinate under treatment but perseverance will very generally cure them in the end.

The best mode of application for cases of incontinence with weakness of the sphincter in women and girls is to introduce a bare metal sound into the urethra as one electrode, and to place the indifferent electrode upon the lower dorsal region of the back. The sound must not enter the bladder for more than a very short distance, otherwise but little current will pass to the walls of the urethra.

For purely nocturnal incontinence, applications to the perineum will usually answer quite as well as the passage of a sound, and the latter may, therefore, be

reserved for the more troublesome cases; the use of a perineal electrode makes the operative procedure more simple and less formidable to the patient. Fig. 79 shows an electrode of suitable shape. It consists of an acorn-shaped piece of metal fitted with a handle, and it is so contrived that its wash-leather cover can be changed in a moment after each application. A ring of vulcanite is pushed on over the piece of wash-leather to hold it in place.

The electrode is to be placed upon the perineum in male children, and at the same place or between the labia in females. The currents used must be decidedly painful in order to produce a suitable impression upon

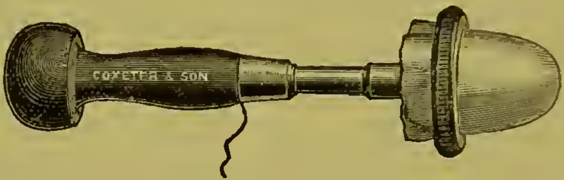


FIG. 79.—Electrode for enuresis.

the nerve centres. It is useless to undertake the electrical treatment of incontinence without direct applications to the perineal region. Where it is desired to avoid all manipulations of these parts the treatment must be done by a nurse, or it may be carried out by applications in an electric bath, using a pad pressed up between the thighs, outside the bathing dress, in place of the ordinary foot plate. The current then passes as desired into the perineal area. It is very important not to allow incontinence of urine in children to be left untreated in the hope that they may outgrow it, because in girls after puberty the local applications may be a source of great embarrassment. In the treatment of

incontinence of either of the types described, the induction coil current applied strongly for eight minutes, and followed by a battery current of five to ten milliampères with reversals every five seconds for three or four minutes, seem to give the best results. The constant current without reversals should not be used for fear of injuring the skin and mucous membrane. Soreness or ulceration may be produced by the constant current unless it be carefully watched.

In retention of urine occurring in hysterical subjects any painful local electrical treatment would probably prove effectual.

238. **Constipation.**—Peristalsis can be set up by electrical currents applied through the abdominal walls, and chronic constipation can be permanently relieved by its use. The poles may be placed one on the lumbar spine and the other on the surface of the abdomen, they should be of large size; the abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. Dr. Wahltuch* has reported seven cases in which the continuous current produced good results. His method was to use a large sponge for the positive pole, and an ordinary medium-sized one for the negative. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, "in the direction of the intestinal canal from the duodenum to the sigmoid flexure," where it was finally fixed, and the current of from five to thirty Leclanché cells allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three to six weeks. The bowels

* *British Medical Journal*, 1883, vol. ii., 623.

gradually became regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Many other writers have reported similar results, and I have myself obtained notably good results in some cases, though not in all.

Another plan, for obstinate cases, is to introduce a bougie electrode (fig. 80) into the rectum, the other pole being kept on the abdomen as before; and to avoid risk of setting up ulceration and soreness of the rectal mucous membrane, a combined douche and electrode has been devised by Boudet de Pâris, and in France a large number of cases have been treated for

FIG. 80.—Rectal electrode combined with douche.

obstinate constipation by means of it, and with great success. It has even been used for cases described as intestinal obstruction. It is obvious, however, that the nature of the intestinal obstruction should be fairly well made out before undertaking to treat it by electricity.

An interesting article on this subject by Dr. Larat, of Paris, will be found in Bigelow's "International System of Electro-Therapeutics."* A similar electrode has been proposed for vaginal applications. The current is conveyed by the stream of water and electrolytic injury to the mucous membranes is avoided.

When there is constipation from want of tone in the

* F. A. Davis & Co., Philadelphia and London, 1894.

muscular walls of the intestines, or of the abdominal muscles, with tendency to flatulent distension, a daily treatment by electricity does much good, and the diminution in the size of the abdomen is easily perceptible after a time.

239. **Sexual disorders.**—Various morbid sexual conditions have been treated by electricity. The nervous supply of these organs is almost identical in position with that of the bladder and rectum, and the seat of application is somewhat similar in both cases.

Erb has advised that a small button-shaped electrode connected with the positive pole be held to the perineum, and another larger electrode (negative) be moved slowly up and down the lower dorsal and lumbar spine. The current may be from five to ten milliampères, according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every other day. In this way the symptoms may be dispelled. Local treatment by means of the wire brush has also been proposed for sexual debility. Electricity is in no way a sovereign remedy for this class of patient, and the restoration of lost sexual powers is generally a vain hope, except where the troubles are mental rather than physical. Even then medical treatment cannot do very much.

240. **Diseases of women.**—Electrical methods are largely made use of in gynæcological practice, not only for the sake of obtaining the direct effects (stimulating, sedative, or trophic) of electricity, but also for electrolysis, and the galvano-cautery (see later chapters). Much attention has been directed to the subject of the electrical treatment of fibro-myoma, and an immense amount of literature has been produced since the introduction of Dr. Apostoli's method of treating

that complaint by electrolysis of the uterine mucous membrane. His methods and results will be considered in the next chapter.

241. **Dysmenorrhœa.**—The effect on painful menstruation of the statical breeze has been referred to in § 108. It is a mode of treatment which is easy and gives good results in many cases. The positive charge with the negative breeze to the loins and spine is not a disagreeable mode of treatment. It should be given daily for a week before the date of the appearance of the menstrual flow.

242. **The vomiting of pregnancy.**—Drs. Gautier and Larat* have described a series of cases, eleven in number, in which the battery current, stabile, arrested obstinate vomiting of this kind. The positive pole is applied above the clavicle between the attachments of the sterno-mastoid muscle, while the negative pole is at the epigastrium, the current should be of eight to ten milliampères, turned on and off very gradually, and continued for fifteen minutes. It may be applied several times daily in severe cases. In from 24 to 48 hours from the first application the vomiting ceases altogether, or is very greatly alleviated.

243. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition for a long time. Dr. Golding Bird† had a very high opinion of the value of shocks from the Leyden jar for curing this symptom, and writes at some length upon it in his little book. His method was to transmit through the pelvis

* "Traitement par l'électricité des Vomissements Nerveux, et en particuliere des Vomissements incoercibles de la Grossesse," Paris, 1895.

† Golding Bird, "Electricity and Magnetism," 1849, Lecture V., and Appendix B.

twelve shocks in succession from a small Leyden jar, the discharge being directed from the sacrum to the pubes. The induction coil current applied to the uterus has also been found efficacious by Panecki and others in patients with amenorrhœa from sluggishness of the uterine functions apart from chlorosis. The electric bath, by its effect upon nutrition, acts as an indirect emmenagogue in chlorosis. When this condition is present general treatment is usually sufficient, and local applications are not called for, and indeed are undesirable. In healthy women in whom menstruation is regularly performed, electricity may certainly hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend general electrical treatment in women for a few days before the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better not to employ electricity at all for abdominal or bladder troubles.

244. **In parturition.**—In a paper read by Dr. Kilner before the Obstetrical Society,* the use of the induction coil current is advocated during parturition. He found that uterine contractions could be excited or strengthened by its aid, though not in all cases. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The applications seemed to diminish the pains felt during the labour, and after the birth of the child ensured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small induction coil in their obstetric

* *British Medical Journal*, April, 1884.

bag. It has also been of service in flooding after miscarriage.

It follows that caution is necessary before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. Dr. Golding Bird speaks of having produced a miscarriage as the result of the Leyden jar shocks used by him.

245. **The mammary glands.**—Electrical stimulation applied to the mammary glands has been found useful for promoting the secretion of milk in nursing women.

Two patients who were suckling their infants were treated in this way in the Electrical Department at St. Bartholomew's Hospital, for failure in their milk producing powers. In one case a decided improvement followed. In the other the results were doubtful. It is not often that the advice of medical men is sought for producing an increase of the mammary secretion.

Cases are quoted by Drs. Beard and Rockwell.

Electricity has also been recommended as a means of increasing the size of the breasts in cases where their development is defective.

246. **Guinea worm.**—In the *British Medical Journal*, vol. ii., 1883, p. 1280, an account of the removal of a guinea worm with the aid of a battery was published by Mr. Alexander Faulkner.

One pole was held in the patient's hand, and the other was applied to the protruding extremity of the worm, the application was continued for an hour with gentle traction, and at the end of that time the whole had been extracted; the usual process of withdrawing the guinea worm little by little by traction for a few minutes daily is a very tedious affair, and may take weeks to complete it, even if the worm is not broken in the process. Mr

Faulkner's explanation of the action of the current is that the worm is benumbed and rendered incapable of resisting.

247. **Suspended animation.**—The aid of electricity is often invoked for the purpose of resuscitation when death appears to be imminent. It may be applied either in the form of brisk general cutaneous stimulation, in cases of narcotic poisoning, or with the special objects of stimulating respiratory movements, or of acting upon the beat of the heart.

In the first case the use of the induction coil, preferably with a long secondary wire and the metallic brush electrode, is advised. The region of the body which is stimulated is not of special importance, the applications may be made to any part which is exposed, and convenient of access.

A considerable reflex effect is produced by this cutaneous stimulation, and if the dry brush and the long wire coil are used there is much less risk of producing fatigue or exhaustion of the patient, than if a short wire coil be used with moistened electrodes (§§ 72, 73). Stimulation of the face, especially of the nose and upper lip, tend to act favourably upon respiration. Duchenne has shown that stimulation of this kind applied to the precordia or to the skin of the back in the lower dorsal region, also influences the respirations. At the former situation inspiration is chiefly promoted, and in the latter expiration.

The phrenic nerves in the neck can be directly stimulated by the induction coil without difficulty, and contraction of the diaphragm will follow. No inconvenience seems to be produced by the proximity of the vagi. The method is as follows :—Two moistened electrodes of small size, about one inch in diameter, must be con-

nected to the coil, one should have a key for making and breaking the circuit. These are to be applied under the posterior border of the sterno-mastoid muscles, which should be pushed forward, the key must then be closed and opened rhythmically about every two seconds, each closure causes an inspiration, expiration being allowed to take place during the intervals. This use of the induction coil to set up respiratory movements may be advantageously combined with mechanical artificial respiration by Silvester's method. Electrical stimulation of the phrenics in asphyxia, and in chloroform poisoning, has been successfully carried out. For further details Dr. F. W. Hewitt's book* may be referred to. Stimulation of the epigastric region may cause expiratory movements by acting upon the abdominal muscles.

Direct applications to the heart region do not readily affect the movements of that organ. If they do, the result is quite as likely to be harmful as useful. It is better therefore not to attempt it.

248. **Electricity as a test of death.**—The electrical reactions of muscle have been proposed as a test of death. The contractility of living muscles persists for a few hours after death, and then disappears.

If the muscles of a person supposed to be dead cannot be caused to contract by a strong induction coil current, life may be considered extinct, if they do contract it is possible that he may be alive. Certainly no person should be buried if his muscles are still normally contractile.

Onimus and Legros† have shown that there is a stage in the death of a muscle at which it gives the reaction

* "Anæsthetics and their Administration," London, 1893.

† "Traité d'électricité médicale," Paris, 1888.

of degeneration (§ 136), that is to say, the irritability to the induction coil disappears first, while the response to direct battery current stimulation continues, giving rise to a *sluggish* contraction. This change sets in about four hours after death, and they relate a case in which the reaction enable them to specify correctly the time at which death had occurred.

CHAPTER XIV.

Electrolysis.

The laws of electrolysis. Actions in living tissues. Uses in surgery. Removal of hairs. Moles and Warts. Nævus. Port wine mark. Aneurysm. Stricture of the urethra, of the œsophagus, of the rectum, of the Eustachian tube. Electrolysis in fibro-myoma. Dr. Apostoli's methods. Extra-uterine fœtation. Cancer.

249. **Electrolysis.**—The laws according to which substances are broken up by the passage of the electric current, and the terms used in considering the portion of a circuit in which electrolysis is occurring, were shortly given in §§ 36, 37. According to the hypothesis of Grotthus the molecules are arranged under the directive action of a current in lines between the anode and kathode, and all along this line a continual decomposition and recombination takes place, which, however, is only manifested at the poles under ordinary circumstances. It is perhaps better to look on an electrolyte with Clausius, as a body whose molecules are continually undergoing dissociation and recombination, even when no current is passing. When, however, an electric stress is set up, there is a directive force brought to bear upon the molecules that are in a free state, and a migration is set up, the electro-negative ions passing towards the anode, the electro-positive ones towards the kathode; if the electric stress is sufficient to overcome the tendency of the dissociated molecules to recombine, decomposition takes place.

Secondary reactions.—The view usually taken is that the actual products of electrolysis are not given off at the electrodes; in general they react with a further portion of the electrolyte or of the solvent, or with the substance of the electrodes, and the products of this secondary reaction appear. Thus, for example, if a solution of sodium sulphate be submitted to electrolysis between platinum electrodes, the ions are sodium and the radical SO_4, but the former instantly decomposes the water present, and forms sodium hydroxide and an equivalent quantity of hydrogen, while the latter breaks up into SO_3, sulphur trioxide, which combines with water to form sulphuric acid, and oxygen, which is given off. The result is that the liquid about the anode becomes acid, while that at the kathode is alkaline. Of course, if the whole is allowed to mix, the two neutralise each other, and the only effect of the electrolysis is that some water has been decomposed.

If the electrodes consist of metals that are capable of being acted on by the ions action will take place and thus the anode will be dissolved if the anion is capable of forming a salt with them, thus a copper anode is rapidly dissolved if used to electrolyse the salts of the mineral acids.

When mixed electrolytes are submitted to electrolysis the most electro-negative ion of the mixture generally makes its appearance first, but it has been shown experimentally by Hittorf that all electrolytes present are concerned.

250. **Electrolysis of living tissues.**—The electrolytic effects produced by a current in passing through the body appear chiefly at the surfaces of the electrodes. These are local effects due to the chemical action of the substances set free by primary or secondary reactions

in the electrolyte. They may be complicated by solution of the anode if it is made of a metal that forms a soluble chloride. Smaller effects may be looked for throughout the body, due to the chemical action between different electrolytes separated by cell walls or other semi-permeable septa, migration of the ions, or transference of the electrolytes due to electrical osmosis. These effects will be seldom perceptible with such currents as are used in treatment.

In a study of the electrolysis of animal tissues, Dr. G. N. Stewart* found that practically the whole of the conduction through animal tissue is electrolytic, and the electrolytes are the saline constituents; the changes produced in the proteids (coagulation, formation of acid and alkali albumen) are brought about by secondary chemical actions. Striking changes in the distribution of the salts can be produced which might be sufficient to modify nutrition profoundly.

In the electrolysis of animal tissues there is a double decomposition. The salts contained in the tissues split up, the alkalies are liberated at the kathode, and the acids at the anode. The alkali metals decompose the water in the neighbourhood of the kathode, liberating the hydrogen, which appears as bubbles of gas. The caustic potash or soda thus produced saponifies the animal tissues and produces a soft deliquescent eschar, which is said to heal with less contraction than an eschar produced by either a wound, a burn, or an acid, and, therefore, is the most suitable to obtain when it is particularly necessary that the least possible contraction shall subsequently take place. The acids from the salts contained in the animal tissues are liberated at the anode; generally oxygen is liberated, but the reaction

* *Lancet*, Dec., 1890.

which takes place at the anode depends very much on its composition. If the electrode is made of zinc, chloride of zinc is formed, which exerts its own specific action on the tissues. By using anodes of iron or copper the local effects of salts of these metal can be produced.

The caustic effect of an electrode connected with the negative pole of a battery has advantages over the use of the ordinary caustic soda or potash. As pointed out by Dr. Poore, it can be applied to parts difficult of access, as the male urethra, or uterine cervical canal. It can be applied to these regions and others, such as the larynx, pharynx, or nasal duct, where the application of other caustics is attended with danger or difficulty. Its effects are limited to the points touched by the electrode. The duration and extent of the caustic action is entirely under the control of the operator.

251. **Uses in surgery.**—Electrolysis is used in surgery as a means for producing destruction of tissue in a simple and minute localised manner. This is effected indirectly by the action of the chemical bodies liberated at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localise the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced although the hair follicle is eradicated. Electrolysis has been used for the following purposes:—(1). The removal of superfluous hair, of moles, and of warts. (2). Destruction of

nævi. (3). Coagulation of blood in aneurysms. (4). Destruction of strictures in the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. (5). Destruction of cancerous growths, and (6) for the relief of symptoms in fibro-myoma of the uterus. This last is brought about as a secondary process which has been found to follow electrolytic destruction of the uterine mucous membrane.

252. **The removal of hairs.**—If a fine needle connected to the negative pole of a battery of four or five cells be introduced into a hair follicle, electrolysis takes place round the needle when the circuit is closed, and the hair follicle is destroyed by the alkali produced; the hair can then be removed easily and does not grow again.

The method of operating is as follows:—The patient should recline in a good light. Having placed the indifferent electrode (anode) in contact with a convenient part of the patient's body, the kathode is attached to a fine platinum wire set in a handle, the current collector is turned on to take up four cells into circuit, the operator then introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle; the needle passes down readily to the required distance, one-eighth or one-tenth of an inch, a current of about three milliampères passes, slight effervescence is seen at the orifice of the follicle, and at the end of five seconds or so the needle is withdrawn. As a rule the hair can then easily be lifted out by a forceps; if it still remains firm, the needle may be introduced a second time until it is loosened, though this is not a very good thing to do; it is rather better to leave the hair until another day; the current should be just strong enough to pro-

duce slight frothing. The best way to learn how to perform the manœuvre is by a few preliminary experiments on oneself. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine need not be applied.

It is best to use for the needle a very fine platinum wire, blunt pointed, because such a needle is less likely to penetrate too easily and so pass away from the hair follicle. It can be sterilised before use by heating to redness, and is better than a steel needle. The current must be closed before the needle has been placed in position. A key in the handle is therefore unnecessary and troublesome.

FIG. 81.—Needle electrode for epilation.

A good deal of practice is required to perform this little operation skilfully, no force must be used in removing a hair, if force is used the hair will come out before the follicle is destroyed, leaving its root behind, and a new hair will grow up from it. When many hairs are to be removed they should be done at successive sittings. Patients as a rule become restless from the pain of the operation after a time, and as soon as signs of this begin to appear, it is best to suspend the operation. It is possible, however, with a good patient, to remove thirty or forty hairs at a sitting. A tiny eschar with a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at one time, for fear less the nutrition of

the skin should be so much interfered with as to lead to a small ulcer and consequent scar, but the hairs should be removed sporadically, until at the last few sittings the few remaining ones can be gleaned off and the place left smooth and bare. If the patch of hairs is small the sittings must be less frequent, once a week being quite often enough. When there is plenty of room to attack a fresh part each time the sittings may be repeated more often, care being always taken not to injure the skin at any one point too much.

It is as well to caution patients that there will be a certain percentage of returning hairs, but that these can be dealt with a second time if any should so return.

It is very easy to overdo the treatment and leave scars. It is not wise to attempt the removal of a fine downy growth on the upper lip of young women.

253. **Trichiasis.**—The removal of eyelashes for trichiasis is satisfactorily accomplished by electrolysis, but it is difficult to carry out owing to the sensitiveness of the part, and the fineness of many of the most troublesome hairs. I have had under treatment several cases suffering from this complaint. In one, at the commencement of the treatment both corneæ were hazy, the result of the continued irritation by the turned in eyelashes; the removal of the eyelashes was persevered with until every one had been removed; by that time the corneæ had recovered perfect transparency. The patient has continued free from trouble from his eyelashes since.

254. **Moles.**—The best treatment for small hairy moles is epilation; when the hairs have been removed very little will be seen of the mole, for a good deal of the pigmentation of the skin between the hairs will disappear when they have been taken out, and the

prominence on which they often grow will also disappear; but if there be much pigmentation the best treatment is by puncturing the mole vertically all over its surface, using a negative needle and seven or eight cells. The cocaine guaiacol mixture (§ 125) can be very well used to render the part insensitive. If the moles are small and pedunculated it is best to electrolyse after transfixing them with the needle.

255. **Nævus.**—Electrolysis is a very convenient way of destroying nævi, and in special cases it is superior to all the other methods, but, to secure first rate results, a certain amount of practice is necessary, and several sittings are required except for the very small ones. The chief art in treating a nævus lies in the careful regulation of the current used and in knowing when to stop. It is easy to electrolyse a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a large scar and is not the best way of attaining one's object. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the blood-vessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is destroyed without any scar except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial, and very florid, and involves the actual thickness of the skin, it is difficult or impossible to destroy it without some sloughing.

The usual plan of treatment is as follows:—Needles attached to one or both poles of a battery are introduced into the nævus, a galvanometer being included in the circuit; the current is then very gradually raised from

zero up to 20, 30 or 40 milliampères. If both poles are used care must be taken that needles of opposite poles do not touch one another, for if they remain in contact the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected; if they come into momentary contacts, the patient receives a shock each time they touch and separate. Soon after the commencement of the operation the tissues round the needles begin to change colour; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. The positive needles become firmly adherent to the tissues in which they are imbedded, and force is required to withdraw them, on this account bleeding is more likely to occur with the positive than with the negative needles. The negative needles become very loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted for reasons already mentioned. If the tissues round the needles become livid or blackened sloughing of the part will follow. This change shows itself first at the negative pole. The position of the needles must be changed before this, by taking them out and re-inserting them one at a time in other parts of the nævus, until the whole of it has been treated.

The nævus becomes swollen and harder during the process of electrolysis, and the skin round it becomes reddened. About five minutes is a suitable length of time to continue the electrolysis, but this should be varied with the size of the nævus. If the nævus is very extensive it must be dealt with in detail, part being attacked at each sitting until the whole has been destroyed.

The needles are to be withdrawn after the current has been lowered and must not be plucked out while the current is still running strongly. The negative needles are easily withdrawn, but the positive may be adherent and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. The after-treatment is simple. Collodion containing iodoform, one drachm to the ounce, is to be painted over the nævus ; this can be left for four or five days, it should then be removed, and the place treated with boracic ointment. If any suppuration or local sloughing should develop, a poultice at night, with some zinc lotion by day, will be a suitable treatment. Many of the smaller nævi dry up and need no second application. It is impossible to avoid some destruction of the skin and scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and when seen a year or two afterwards they show remarkably little. Sometimes only one set of needles, usually the negative, is introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is higher, so a larger number of cells is required. There is a greater risk of shock or faintness, especially with nævi of the head and face, but with care the operation can be carried out successfully. This unipolar method is most suitable in cases where great nicety is needed, as, for example, in small nævi about the eyelids or nose.

Care must be taken that the pad electrode and its conducting wire are well covered and that no bare metal touches the skin anywhere, any oversight in this matter may lead to electrolysis where it is not wanted, namely, at the seat of the indifferent electrode.

The rate of destruction depends upon the density (§ 112) of current in the part; if needles of both poles are introduced irregularly, it is very likely that the current may be concentrated round the points where they are nearest together, and be very ieeble in the more remote parts. The diagrams (fig. 82 and 83)

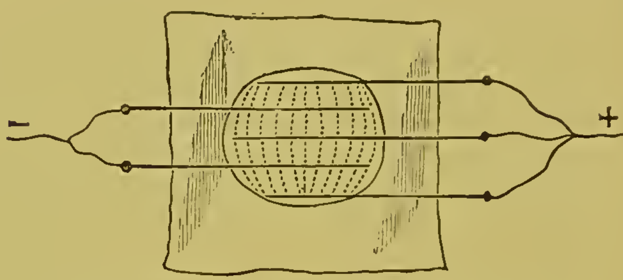


FIG. 82.—Electrolysis of nævus. Proper position of needles.

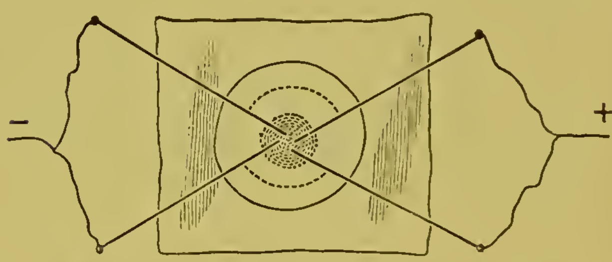


FIG. 83.—Electrolysis of nævus. Improper position of needles.

represent the conditions under two different arrangements of needles, in the first the needles are placed in such a way as to be equidistant, and the density of current is therefore uniformly diffused. In the second, they are all very near together at the points and there the current is of far greater density than at the periphery of the nævus, the effect of such an arrangement

would be to produce a slough at the centre, while the periphery would not be destroyed at all. In order to simplify the introduction of the needles in a proper manner, the writer* has devised an instrument (fig. 84) consisting of a handle to carry the needles; two, three, four or five can be screwed into it, and they are so arranged as to be alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances from one another throughout the operation, and they cannot touch accidentally, and they can be moved about

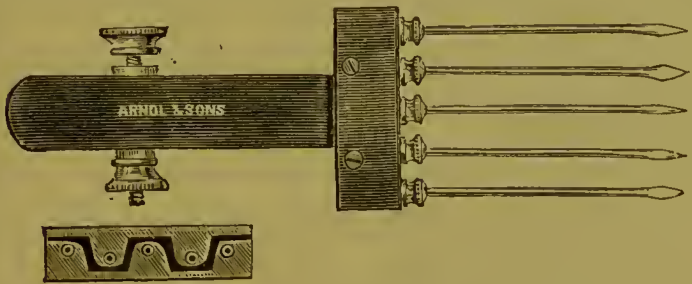


FIG. 84.—Bipolar fork electrode.

simultaneously inside the nævus so as to bring the whole of it under the action of the current.

It is difficult to formulate a rule for the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. The current density should not exceed twenty milliampères per inch of positive needle if it is desired to avoid sloughing in a nævus. Thus, with four needles introduced for a distance of one inch, two being positive, a current of forty milliampères would be amply sufficient, and with twice the

* Dr. Lewis Jones, *Brit. Med. Journal*, Feb. 20, 1892. "An mproved instrument for the electrolysis of nævi."

number introduced for half that distance the same current would yield the same effects.

The cells of an ordinary portable battery will do very well for the occasional electrolysis of nævi, but as the current required tends to exhaust small cells rather fast, it is better to use larger ones when portability is not essential. The galvanometer must read up to fifty milliampères. From twelve to twenty cells are sufficient.

The usual arrangement of wires for the attachment of the needles is shown in fig. 85. It consists of two parts, (1) a main lead from the pole of the battery, terminating in a binding screw, and (2) several secondary leads or branches, each carrying a needle, and attached to the binding screw of the main lead. The needles should be of platinum. Insulation of the needles is not important, and it is difficult to obtain an insulating coat which does not greatly increase the thickness of the needles and act as an obstacle to its introduction. Hard varnish, applied each time, is the best. The intention is that the whole of the bare part of the needle must be buried in the nævus, in order that an insulated part may be in contact with the skin, which is then attacked but little, and this diminishes the size of the marks which will be left at the points of entry, and for this reason needles are required whose bare points are of varying length. When needles of one pole only are used, the other (indifferent) electrode must be a pad of good size, to diminish as much as possible the density of current at its surface of contact, and also to diminish the resistance.

Care must be taken to prevent any spare needles from touching the patient's skin by accident, or they will corrode it at the point of contact.

The needles are attached to the ends of the wires in various ways. Soldering is much the best. Unions

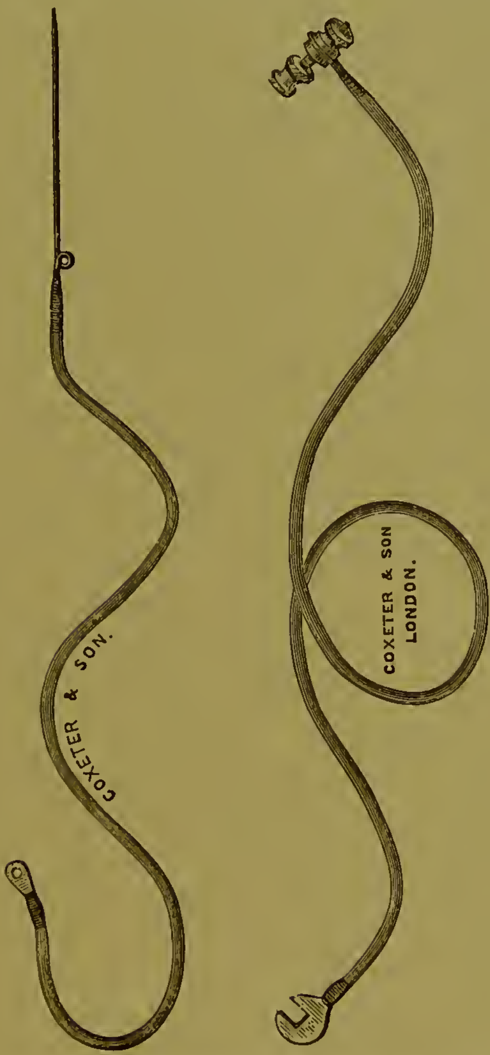


FIG. 85.—Attachment of needles for electrolysis of nævus.

effected by twisting the wire round the needle are bad, for they are apt to break adrift at a critical moment

and give rise to shock. With large currents such shocks are undesirable in the case of infants under chloroform.

An anæsthetic should be given as the pain is severe during the passage of the current, though it does not persist after the operation is over.

The needles may be introduced either in a direction parallel to the surface or vertically; the former is the best when the nævus has any appreciable thickness.

In some superficial nævi a multiple puncturing with a vertical needle gives the best results, sufficient skin survives between the punctures to preserve the mark from being truly cicatricial.

The electrolytic treatment of nævus is not so simple a matter as it may appear to be at first sight. Those nævi which can be easily excised should not be attempted by electrolysis, which should be reserved for those which are difficult to do by other methods. If the nævus is very small, that is to say, under a fifth of an inch in diameter, it may be completely destroyed in one sitting, and the resulting scar will not be of any great moment; and here I would urge very seriously the importance of dealing with nævus at the first possible opportunity after birth. Nævi which are quite small at birth are often allowed to grow large before any interference is thought necessary, with the result of disfigurement, which might have been prevented by timely treatment. They should always be attacked at once. Unless nævi are large, the first application should aim at complete destruction, or at least the major part of the nævus should be got rid of at the first treatment.

Nævi may spontaneously disappear, but this is a rare occurrence, and the usual tendency of a nævus in the

young baby is to grow rapidly. Indeed, after electrolysis, a nævus will often commence to grow afresh, although at the time of operating it seemed to have been completely destroyed. Such re-appearance may take place after a nævus had been perfectly healed for over two months. The margin of a nævus is especially prone to start fresh growth, and must be treated as thoroughly as possible.

Nævus is commoner in females than in males, and it is found on the head and neck more often than upon the trunk or limbs. Out of 173 consecutive cases in the Electrical Department of St. Bartholomew's, 121 were in female, and 52 in male children; in about three-fifths of these the nævus was situated on some part of the head or neck. I have once seen a nævus of the ocular conjunctiva. At the anterior fontanelle it is not uncommonly met with, and can safely be treated by electrolysis; the needles of course must not be pushed into the brain.

256. **Metallic electrolysis.**—The use of copper needles for electrolysis has been advocated under this name, the intention being to deposit a salt of copper in the nævus or other tissue under treatment. More marked effects can be produced by copper than by platinum needles, and the metal does not appear to leave any permanent stain. The positive pole must be used. Instead of copper needles the ordinary platinum needles can be coated with copper electrolytically in a bath of sulphate of copper, using a piece of copper sheet for the anode and making the needles to be coated the kathode of a battery of one or two Leclanché or other cells; the process only takes a few minutes, and the needles can then be taken out, washed and used for electrolysing a nævus. With copper needles the visible

effect is rather different to that of electrolysis with the negative pole and platinum needles, and therefore a certain amount of practice is required before one becomes an adept with the coppered needles; but good results can be had, and especially when a more thorough destruction of a part is desired. The tissues round the needle turn of a dull greenish colour. The negative pole must be used in the form of a pad electrode, as the deposition of copper from the needles takes place only at the positive pole.

257. **Port wine mark.**—This form of nævus can be attacked by a tattooing process, using a fine needle, and inserting it vertically into the skin, the current used must be under five milliampères, and the application at each point quite brief. There is no need to use several needles at once. The operation should produce minute points of destruction without confluence of the resulting minute scars. The negative pole is best. If a port wine mark be closely scrutinised, the position of many of the capillaries can be seen, and these are the points into which the needle must be especially directed. The area affected must be treated in a sporadic manner at successive sittings as advised for the removal of superfluous hair. The result is a distinct improvement in the aspect of the surface; the treatment must be carried out slowly. It is so slow a process that it is not often undertaken.

258. **Aneurysms.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded, some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of

the wall of the aneurysm by the needles, with the consequent risk of bleeding is the chief defect of the operation; it may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour; the needles attached to the positive pole become corroded if they are made of steel, but this is not an objection, for coagulation is promoted by the salts of iron so produced. Ciniselli* has collected twenty-three cases, of these six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had relapses a few months later. See also *Brit. Med. Journal*, 1890, vol. i., p. 1276, for a report of successful results after thirteen sittings in a case of aortic aneurysm.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty, or forty cells have been used, and the application continued for half an hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt a piece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current if continued for half an hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies produced by the

* "Treatment of Thoracic Aneurysms by Electro-puncture," Milan, 1870.

electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood stream. The clotting set up in the aneurysm is soft and diffluent.

259. **Stricture of the urethra.**—Modern writers on this subject refer to Crussel, 1839, as the first to use electrolysis for the cure of this condition, and to Mallez and Tripier* as the first to practice it systematically. A good deal has been made of the difference between electrolysis of a stricture, and destruction of it by the caustic alkali set free electrolytically at its surface, as though the former process were something essentially different and less injurious than the latter. It has also been claimed that the stricture can be cured without any destructive action upon the mucous membrane which covers it. It is probable that the yielding of a stricture during electrolysis is mainly due to its actual corrosion by the alkali liberated at the negative pole, and that the mucous membrane, because it is nearest to the electrode, must be the first part to perish, but it is possible that the current produces some interstitial absorption of the tissues of the stricture, in the way referred to in § 230.

Mr. Bruce Clark in a paper on the subject† says :—"Where I have had an opportunity of treating an orifice stricture it is clearly demonstrated that with such currents as one usually employs, no solution of epithelial continuity takes place," and again :—"That absorption does take place can be witnessed when a stricture at or within half an inch of the urethral

* "De la guerison durable des rétrécissements de l'urethre par la galvano-caustique chimique," Paris, 1867.

† "The Treatment of Stricture of the Urethra by Electrolysis," *The Practitioner*, 1886.

orifice is submitted to treatment. In these cases the surface of the epithelium is seen to be gradually converted into a glutinous saponaceous-looking material. If this be wiped carefully away, the surface is seen to be red and somewhat congested in appearance, but it is perfectly evident that the epithelium is not entirely removed with such currents as I am in the habit of employing."

In a paper read at the Annual Meeting of the British Medical Association, in 1886, by Dr. W. E. Steavenson, the following account of electrolysis of stricture occurs:—"No doubt this procedure will become one of the recognised modes of treatment of stricture. It may not be destined to become the most usual mode of treatment, because of the apparatus required, the numerous details connected with its application, and the great care and patience required for its successful employment.

"For the treatment of stricture of the urethra, the electrodes we have used are catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece connected to a binding screw on the handle. The indifferent electrode is placed upon the patient's back if he is in the recumbent position, or it may be placed on any other convenient part of the body. The metal plate is made positive.

"An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that

the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with the negative pole of the battery, the circuit is closed and the current gradually increased without breaks until the maximum strength is reached that it is intended to employ, namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. No force is used, but the current is allowed to do the work. The surgeon has to keep his attention continually applied to the electrode, so as to guide it in the right direction, otherwise a false passage may be dissolved into the side of the urethra. Therefore skill in passing a catheter is a requisition. In the hands of a surgeon who knows his way into the bladder, a false passage is not more likely to be produced than is the case in passing an ordinary catheter. The electrode is to be kept gently pressed against the stricture in the normal direction of the urethra until, from the dissolution of the obstacle in front of it, it passes into the bladder. The current then should immediately be cut off, and the bougie withdrawn. The duration of the operation depends upon the density of the stricture and the strength of the current used.

"Although as a guide I have mentioned that the current should be about six milliampères, the strength really used is regulated by the patient himself. One great object is to avoid giving pain, and by this means a too great destruction of tissue is prevented. We require our patient to be conscious; therefore no anæsthetic is used, or indeed necessary, for the only sensation produced is a slight pricking at the seat of the

stricture. If anything amounting to pain should be complained of, the strength of the current has to be diminished. On removing the electrode, there is some times found on it some slimy matter like disintegrated tissue; and the patient is often immediately after its withdrawal enabled to pass urine with increased facility and with very little discomfort. After the operation we have left the patient entirely free, without any interference, for usually the space of ten days or a fortnight, and then have tried what sized bougie would pass. If no disintegrated tissue comes out upon the electrode, some sort of slough or eschar is thrown off at a later period—the next day, or a day or two after the operation, during the passage of urine.

"Going back to the example we have already taken, if, after dissolving the stricture, it has been possible to pass a No. 5 electrode into the bladder, after the rest of a fortnight it is usually found that a No. 7 bougie can be passed. Should that be the limit of the increased calibre of the passage, a No. 9 electrode is taken, and the same operation repeated as before described, and so on after the interval of another fortnight, until the stricture is cured. The results of our investigations may be summed up as follows:—In the treatment of stricture of the urethra by electrolysis, there is usually no bleeding. If hæmorrhage does occur, it is accidental, and usually shows that a too strong current or the wrong pole of the battery has been used. No anæsthetic is required. It is an assistance to the operation that the patient should remain conscious. The pain or discomfort produced is trifling. The patient can in the case of a slight stricture pursue his ordinary occupation during the period of treatment. In the majority of cases there is no contraction or return of the stricture.

"Eschars formed by caustic alkalies are said to heal with less contraction than wounds produced in any other way, and electrolysis with the negative pole is a means of applying the destructive action caused by the caustic alkalies to parts difficult of access, and in a way which is impossible by any other method. But beyond this, the current appears to set up an absorptive action around and within the dense cicatricial tissue which forms the stricture, so that it gradually disappears. This we have seen in several ways. After electrolysis has proceeded so that the electrode will pass into the bladder, it is found a fortnight later that a bougie of two sizes larger can be passed. Additional absorption must therefore have taken place in the interval. And again in penile strictures, where we have been able to feel the hard dense tissue of which they are formed, a few days after electrolysis we have noticed that this hardness has disappeared.

This progressive improvement after the termination of treatment is very remarkable, and lends some colour to the belief that an actual absorption of fibrous tissue may be determined by the passage of the current. It has also been stated that the cure is more permanent than it is after ordinary dilatation. For reports of Mr. Bruce Clarke's cases, with their subsequent history, see *Practitioner*, 1886, and *British Medical Journal*, 1890, vol. i., p. 942.

In a letter written to me in 1892, Mr. Bruce Clarke stated that he still considered the results of electrolysis to be extremely good and permanent in cases of stricture. Of a patient who was treated by him in 1885, he wrote:—"I saw him a few days ago, and passed a No. 11 with the greatest ease. No instrument has been passed since the operation, except by myself once or

twice for purposes of diagnosis." The use of electricity for the treatment of stricture is under the disadvantage that it offers no special superiority over the other modes of treatment. These are sufficient for the ordinary needs of the cases, and the electrical method is therefore superfluous.

The electrical treatment of any disease in order to justify its existence must offer results which are superior to those which can be had in other ways, and apparently surgeons do not find it necessary to use electrolysis in stricture of the urethra because they can obtain the required results without it.

260. **Other strictures.**—Electrolysis has been recommended for stricture of the œsophagus by most writers on medical electricity. Stricture of the rectum can also be treated by means of electrodes shaped like rectal bougies, which are connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

261. **Eustachian obstruction.**—In the *Lancet* for Nov., 1888, a paper on electrolysis of the Eustachian tube was published by Mr. Cumberbatch and Dr. W. E. Steavenson. The authors described their methods as follows:—"The instrument consists of a vulcanite Eustachian catheter and an electrical bougie (fig. 86), the bougie is made of a fine flexible copper cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The ends are

soldered into a nickel plated cap. The bougie is small enough to pass along the catheter, and exceeds it in length by about an inch. The handle end of the bougie is provided with a binding screw, to which the insulated copper wires are also attached, for the purpose of connecting a rheophore from the battery. On this end of the bougie an inch is marked off divided into eighths. Each eighth of the inch passes into the catheter as one eighth protrudes at the other end. It is therefore possible to tell, when the catheter is in the orifice of the Eustachian tube, how much of the bougie is in the canal. On the catheter there is a metal ring, or some

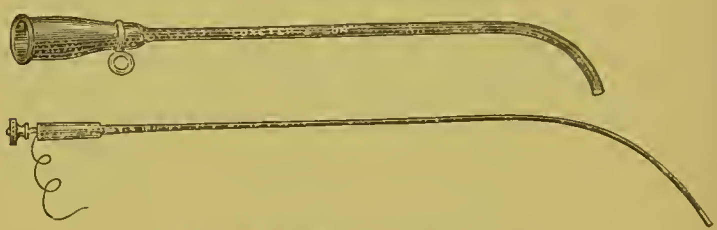


Fig. 86.—Eustachian catheter electrode.

other mark, to indicate the direction of its end when it is being inserted.

"Electrolysis of the Eustachian tube is performed in much the same way as the electrolysis of the other mucous passages. A pad connected with the positive pole of a battery is moistened and placed at the back of the patient's neck. The Eustachian catheter is then passed along the nostril and guided into the tube; the bougie already attached to the negative pole of the battery, is passed along the catheter and Eustachian canal as far as it will go, until it meets an obstruction. The circuit is then closed. A galvanometer should be included in the circuit, and the current gradually in-

creased up to four milliampères. A frizzling noise will be heard by the patient in his head, and the operator, by approaching his ear to the catheter, may hear the crackling produced by the breaking of minute bubbles of gas. The electrolysis is kept up for four minutes, and usually before the expiration of that time, if it is possible that the obstruction can be removed, it will be found that the bougie can be pushed on for a small distance, sometimes for its full length. Generally on the first occasion the Eustachian tube is rather sensitive, but it seems to acquire toleration for the process, and at no time is so much discomfort experienced as might be expected. The operation has now been performed a large number of times without any unpleasant experiences, nor has the treatment caused any pain, either at the time or afterwards.

"In favourable cases there is an immediate improvement in the hearing, as tested by the greater distance at which a watch can be heard after the passage of the instrument; the distance at which it is heard may be doubled. In other cases the results are not so good, partly from the difficulty of reaching the Eustachian tube, and partly no doubt from other causes." This method has fallen into disuse.

262. **Lachrymal obstruction.**—In a paper by Mr. Jessop and Dr. Steavenson,* an account is given of ten cases of lachrymal obstruction treated by electrolysis. The advantage of the method is again due to the ease with which the action can be confined to the exact parts needing treatment. The instrument used by them is a curved platinum probe. The operation is very simple; the current required is small, two to four milliampères being sufficient, and the duration is thirty

* *Brit. Med. Jour.*, 1887, ii., p. 371.

seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual pad indifferent electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the punctum or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

263. **Electrolysis for uterine fibroids.**—Since the publication by Apostoli of his method of treating fibromyoma, an immense amount of literature has been produced on the subject. Much has been said both for and against Apostoli's* treatment, and the enthusiasm which was at first shown in his favour by many writers, has to a large extent been followed by a reaction against it. There is no doubt, however, that electrolysis may hold a place in the treatment of fibroids, because it offers an alternative to the very serious operation of abdominal section, and in many cases it affords great relief to the symptoms of the patient, even if it does not effect a radical cure of the disease. What has been written above of electrolysis in stricture of the urethra applies also to the electrical treatment of fibroids, namely, that the electrical method competes with other surgical modes of treatment without offering any decided advantages, and in consequence it is neglected as being unnecessary, at least in this country. In the absence of any personal experience of the matter I propose here to give a short abstract of Dr. Carlet's† original

* See the medical journals, 1888, 1889, and publications by Drs. Steavenson, Bartholow, Keith, Massey, Engelmann and many others.

† "Le traitement électrique des tumeurs fibreuses de l'uterus," Dr. Lucien Carlet, Paris, 1884.

paper, produced under the immediate direction of Dr. Apostoli.

The early attempts at treating fibroids by electrolysis were done by Cutter, 1871. Routh and Althaus, 1873. Brachet, 1875. Semeleder, 1876. Everett, 1878. Aimé Martin, 1879. Gallard, 1881. In 1882 Apostoli communicated a paper to the Académie de Médecine, in which he described his method of procedure. He recommended an internal positive electrode of platinum, and an abdominal electrode (negative) of moist china clay of large surface, and a continuous current of sixty to seventy milliampères, for from five to fifteen minutes. In certain cases when the internal electrode could not be passed into the cavity of the uterus, he thrust it through the cervix into the tissue of the uterus instead. Sittings once or twice a week. The action of the current was to produce destruction of the uterine mucous membrane. The results were to reduce the size of the uterus, and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process of repair, by a process of involution, and by a cicatrisation which checks the metrorrhagia.

Drs. Apostoli and Carlet arrange their account of the operation as follows:—

1. *The seat of the operation.*—It must be intra-uterine, and the internal electrode must occupy the whole depth of the uterine cavity. To puncture the uterus from the abdomen is dangerous, for suppuration and peritonitis are likely to follow, adhesions are likely to be formed, and the uterine mucous membrane is not touched.

2. *The nature of the operation.*—The positive pole is indicated for the internal electrode when hæmorrhage is the chief symptom, the negative pole may be used when the fibroids are large, hard and subperitoneal, and

when there is not much hæmorrhage, for if anything it increases the tendency to bleeding.

The current must be quite uniform, and must be raised and lowered very gradually, sudden interruptions with the large currents used are sufficient to give dangerous shocks.

3. *The strength of current.*—The maximum strength which the patient can bear is to be employed; when the uterus is large, a greater strength is needed to produce the same density of current (see § 112). Cauterization is easily obtained in an uterus of little length owing to the smaller surface for distribution of the current, but a much greater current is needed with a lengthened uterus, owing to its greater area. One hundred milliampères is the mean strength used by Apostoli since 1883 (date of Dr. Carlet's paper, 1884), and this is generally well borne by the uterus. In hysterical patients the current is not well borne, or rather a fit may threaten, unless the current is very cautiously increased. The operation must not be undertaken during acute perimetritis (or any other febrile condition).

4. *The duration of the operation.*—The mean duration should be from five to ten minutes, according to the gravity of the case and the tolerance of the patient. When patients have to return home immediately afterwards, five minutes suffices in most cases. A strong current for a shorter time is better than a lesser current for a longer time.

5. *The number of sittings.*—An absolute cure with complete restoration to health (*ad integrum*), is and will ever be, beyond our medical resources. Our hope is that we may reduce the size of the tumour by one-half or one-third, and remove the symptoms. Whether the tumours persist or not, the operator should persevere

until the symptoms are relieved, and he ought not to be satisfied till this goal is reached. "He should depend on the general condition and statements of the patient, and not on what digital exploration reveals."

Twenty or thirty sittings is the mean number, but many patients declare themselves cured after five to ten sittings. "If after great amelioration the patient desires to gain all she can from the treatment, it may be resumed, but the progress will be much more slow than at the commencement."

6. *Choice of time.*—When pain and losses are not very great and other symptoms are not acute, choose the inter-menstrual period, but on the other hand, with serious symptoms making life miserable or endangering it, begin at once, even during severe bleeding.

The intervals between sittings should be long enough for all pain or discharge produced by the previous ones to have ceased. The operation may be performed once a week, or even twice a week if the patient is able to keep her head or to remain very quiet.

7. *Technical details.*—Before commencing, explain to the patient what is going to be done, make sure that the battery is in good order, and that all wires and connections are sound, disinfect the internal electrode, adapt the abdominal electrode of potter's clay carefully to the surface of the skin, first covering any little abrasion or acne spot, however small, with a piece of oiled silk or guttapercha tissue. The patient must remove her stays and loosen all her skirts, and the abdomen must be quite bare. She must recline on her back on a couch or across the bed, the vagina must be thoroughly syringed out; finally she must be assured that the operation will not be very painful, and that at the slightest sign from her the strength of current will be

reduced, on the other hand she must be encouraged not to complain unnecessarily; place the clay electrode on the abdomen, see that its margins do not touch the groins or pubes, attach the battery wire, then introduce the internal electrode with great care and gentleness. (This is the most difficult part of the operation, and it may be better to do it before applying the abdominal electrode). Make sure that it has passed to the full length of the uterus, examine to see that the vagina and vulva are perfectly shielded from metallic contacts, and encourage the patient to press with her palms upon the clay electrode, so as to keep it well applied. Do not commence the current till all pain from the introduction of the electrode has passed off. After the operation tell the woman that she will have pains for a few hours, and a slightly tinged discharge for a day or two. She must rest for two hours before going home, and must then lie down. Walking exercise is bad. Conjugal relations must be absolutely forbidden.

Weak injections of Condy's fluid or carbolic lotion should be used once daily.

The intra-uterine electrode has the shape of a sound, insulated except at its extremity, this part must be of platinum, and its length should be capable of adjustment to suit the length of the uterus. The insulation should reach sufficiently far to protect the cervix uteri as well as the vagina. Care must be taken that no bare metal touches the vulva, or the skin of the thighs, or a painful sore place will be produced.

Dr. Apostoli's sound (fig. 87) was fitted with a sliding vulcanite sheath; platinum pieces, either sharp or blunt, are screwed into the end of the shaft, and are chosen of a length to suit that of the uterine cavity. Subsequently Steavenson modified and improved the

original pattern by making an electrode shaped like a hard rubber catheter with a platinum tip (fig. 88). The advantage of this shape is that the instrument is more flexible and more easily introduced into the

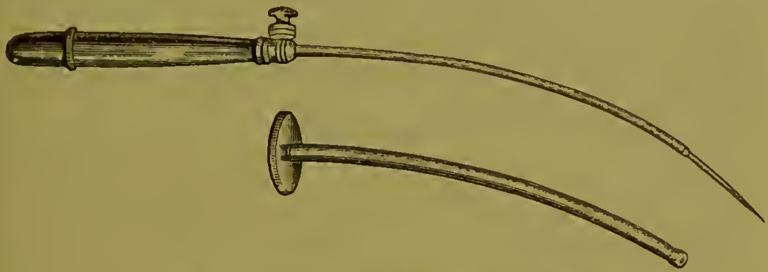


FIG. 87.—Apostoli's uterine electrode and sheath.

uterus, and the insulation part is not thicker than the rest, therefore, it can enter more easily into the cervix so as to protect that part. If this form of electrode be used it will be necessary to have a set with platinum

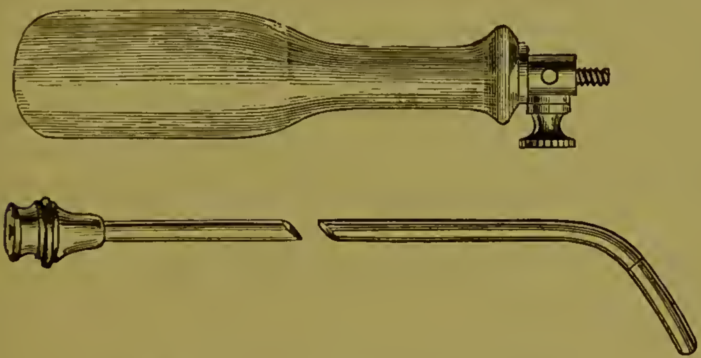


FIG. 88.—Steavenson's electrode for fibro-myoma.

ends of different lengths, whereas Apostoli's sound can be altered to suit each case by means of changing the platinum points.

The electrodes with sharp points are made for

puncturing the uterus when the cervical canal cannot be reached. Puncture, however is now very rarely practised.

An ordinary uterine sound made with a platinum end and fitted with a binding screw answers the purpose very well; the stem can be insulated by a thin soft rubber tube slipped over it, leaving bare the appropriate length at the end. The edge of this soft tube will enter the cervical canal quite well, especially if it be painted over with a little collodion to fix it. The advantage is that such an instrument can be kept absolutely clean, a new piece of rubber being slipped on for each operation and a little vaseline smeared over to protect against any possible escape of current through minute holes in the rubber.

The abdominal electrode is prepared by making up a putty like mass with the potter's clay and water, it is then spread out evenly on a piece of muslin in a layer half-an-inch thick. A metal plate with binding screw is embedded in its upper surface, and the muslin is folded over to enclose a round cake of the clay. It should measure about nine or ten inches in diameter.

The preparation of this electrode is rather troublesome, and it is heavy and rather messy for the patient, but it adapts itself well to the surface of the abdomen and gives good results. Substitutes for it have been devised, such as large flat bags of bladder or dialysing parchment containing warm water or pads of wood pulp. These will also adapt themselves very closely. Metal plates covered with moistened flannel, or carbon in small lumps covered with flannel to form a cushion have also been tried.

A firm cake of gelatine also conducts very well, and is easily prepared by liquefying some gelatine and pour-

ing it out into a small plate, a metal pad can be fixed to it when it has set, by laying it on the surface and pouring more gelatine over it. It is rather sticky and unpleasant, however, as it has a tendency to melt at the temperature of the body. The addition of one or two per cent. of alum will prevent this, and will improve the pad, which is to be enclosed in muslin, and used exactly as the clay electrode. It is much more cleanly and agreeable.

Bergonié and Boursier have published the notes of a hundred cases in which they carried out Apostoli's treatment for fibro-myoma, and they give the following summary of their views* :—" The electric treatment of fibro-myoma is undoubtedly efficacious as a palliative method of treatment. When hæmorrhage was the chief symptom complained of 90 per cent. were relieved. The general state of health was improved in 79 per cent., the symptom of pain was relieved in 50 per cent., while a decrease in the size of the tumour was observed in ten per cent. only."

264. **Extra-uterine fœtation.**—Attempts have been made to arrest the progress of extra-uterine fœtation by electrical treatment, and cases which appear to have been successful have been recorded, most of them in America.

In the *St. Bartholomew's Hospital Reports*, vol. xix., 1883, Dr. Matthews Duncan and Dr. Mason published a paper on extra-uterine fœtation, with an account of one case in which the pregnancy had lasted five months and the fœtal heart was audible. Electrolysis was practised on two occasions with a fortnight's interval. The current of forty cells was employed for six minutes, on the first occasion the poles were in the vagina and

* *Arch. d'Electricité medicalé*, 1893, 211.

on the abdomen respectively; on the second occasion two needles connected with the negative pole were thrust into the tumour while the positive was applied to the abdominal surface as before.

The fœtal heart was not arrested on either occasion. Other means of destroying the fœtus were then employed, and the patient died of peritonitis a week after the second sitting; post-mortem the fœtus was found very considerably macerated, this was considered to have been due to the electrical treatment.

Dr. Percy Boulton* has published a case of early (six or eight weeks) extra-uterine fœtation, where electrolysis proved fatal from peritonitis, but there was no post-mortem examination to show what changes had been set up in the tumour. The case shows that electrolysis, even in the early months, is not free from danger.

Mr. Lawson Tait and other speakers at the Brighton meeting pointed out that very often tubal pregnancy may undergo spontaneous cure. It is very likely that some of those said to have been cured by induction coil shocks were really cases of this kind, because it is difficult to see how a moderate induction current, diffused through the large sectional area of the abdomen, could exert any effect at all upon the tissues of a young fœtus, though it might possibly produce some mechanical compression by setting up tonic contraction of the muscle fibres in the Fallopian tube round it. To slay even a small animal it is necessary to have very large currents, carefully concentrated upon a vital part. A fœtus lying in the midst of the conducting tissues of the abdomen could only receive a small fraction of the comparatively small current yielded by a medical coil.

* *Brit. Med. Journal*, April, 1887.

265. **Cancer.**—The destruction of cancerous tumours by electrolysis has been proposed.

Although it is not likely that electrolytic treatment will do more than produce sloughing of parts of a cancer, yet it is sometimes useful, when nothing else can be done, because the pain of the cancer is often much diminished after electrolysis, as has been observed by Althaus. Cures of cancer by electrolysis will be found reported in many of the books on electrical treatment, but a close study will usually reveal some weak point in the history of the cases related.

CHAPTER XV.

Cautery and Lighting Instruments. The Electro-Magnet.

The galvano-cautery. Batteries for cautery purposes. Accumulators. Wires and leads. Lamps. Batteries for lamps. The use of electric light mains. Rheostats. The cystoscope. The panelectroscope. The electro-magnet.

266. **The galvanic cautery.**—The forms of galvano-cautery in common use are numerous, but their plan of construction depends upon one general principle. The cauteries used for small operations consist of small loops of platinum wire mounted on straight or curved copper supports, which are insulated from each other, and then bound together to form a convenient stem

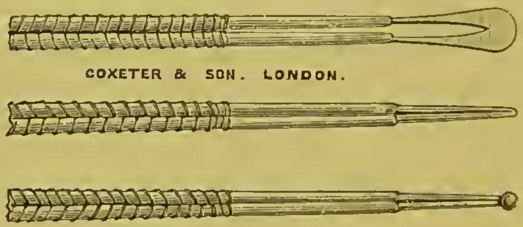


Fig. 89.—Platinum cautery points.

(fig. 89). These fit into a handle provided with binding screws and a key for easily opening and closing the circuit. The platinum loops, having a relatively high resistance, become heated by the passage of the current. The figure (fig. 90) shows an usual form of handle,

known as Schech's, which is made in two sizes. For most operations the shorter handles are more convenient than the large size, which is too unwieldy for delicate manipulations.

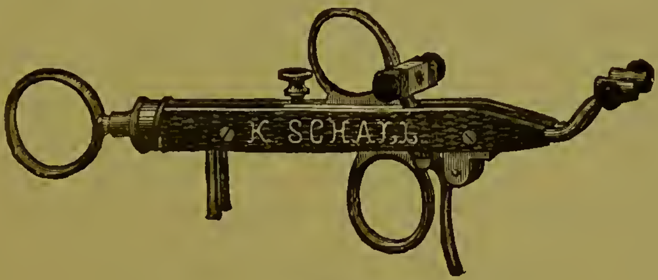


FIG. 90.—Schech's handle.

For fine work a very nice handle is made in the shape of a metal pencil case, (fig. 91). Connection is made by a twin wire with a plug which fits a socket at the end of the handle, the switch is a ring of metal sliding over a piece of ivory. This form of cautery

FIG. 91.—Cautery handle.

handle is much the most convenient for small work, and whenever burners mounted on long stems are not required. Its length is five inches.

The current which heats the platinum points heats the cautery mounts as well, in a less degree, the current, therefore, should only be left on when the cautery is in actual use. The supports are insulated by a thick waxed thread twisted round them in racking turns, which keeps them from touching, although binding them together, and forms a sufficient means of insulation, except when they become overheated.

Besides the simple platinum loops, cutting instruments of various shapes are made by hammering the platinum flat or by bending it in various ways. Where a larger incandescent surface is required, a loop or spiral of platinum supported in grooves on a porcelain mount is made, the porcelain then becomes heated to redness as well as the platinum (see fig. 92). Different thicknesses of platinum wire are used, and accordingly the current required varies greatly in different cauteries.

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, and a screw can be mounted on the handle

FIG. 92.—Cautery for larger incandescent surface.

figured above for gradually drawing up the wire loop when it is hot. It is as well to mention that the temperature of a cautery must not be allowed to rise above dull redness. At a white heat the cauterising action is so rapid that searing of the surface does not take place, and hæmorrhage may follow as profusely as after division of the tissues by a knife. A large number of modified forms of cautery and mount will be found in the instrument makers' catalogues. The resistance of the cauteries just described may vary from ·025 to ·04 ohm.

The current required to bring the platinum loops to redness varies between eight or ten ampères for the smaller, to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

In the prostatic cautery of Prof. Bottini* the part to be heated consists of two strips of platinum, each 20 mm. × 8 mm., which lie side by side in the concavity near the beak of an instrument, which is shaped like a vesical sound. The current passes along one strip and returns by the other. The large mass of the platinum makes the resistance of the part to be heated remarkably low, about ·0005 ohm, and consequently an immense current, amounting to fifty ampères, is required to raise it to a red heat. Such a current as this taxes any portable battery to the utmost. This instrument is used for the radical cure of the symptoms caused by enlarged prostate, and its use has been advocated in this country by Mr. Bruce Clarke,† who has employed it successfully on several occasions.

267. **Cautery batteries.**—The batteries of small cells which are used in medical treatment are arranged for high electromotive forces with the minimum of weight, and their internal resistance is of little importance. For cautery purposes the conditions are quite different, and the small medical cells are therefore unsuitable. Large bichromate cells have been much used for cautery purposes, but they are rather troublesome to maintain, although they may be made to yield a large current for a brief period. Fig. 93 shows a form of this battery which is strong and good, and may be easily arranged as a two cell battery with pairs of cells in parallel for cautery purposes, or as a four cell battery for electric lamps (see § 270). In places where storage cells cannot be used this form of cell must be had recourse to.

* *Brit. Med. Journal*, 1891, vol. i., p. 1121. Description and figure.

† *Proceedings of the Medico-Chirurgical Society*, Jan., 1892.

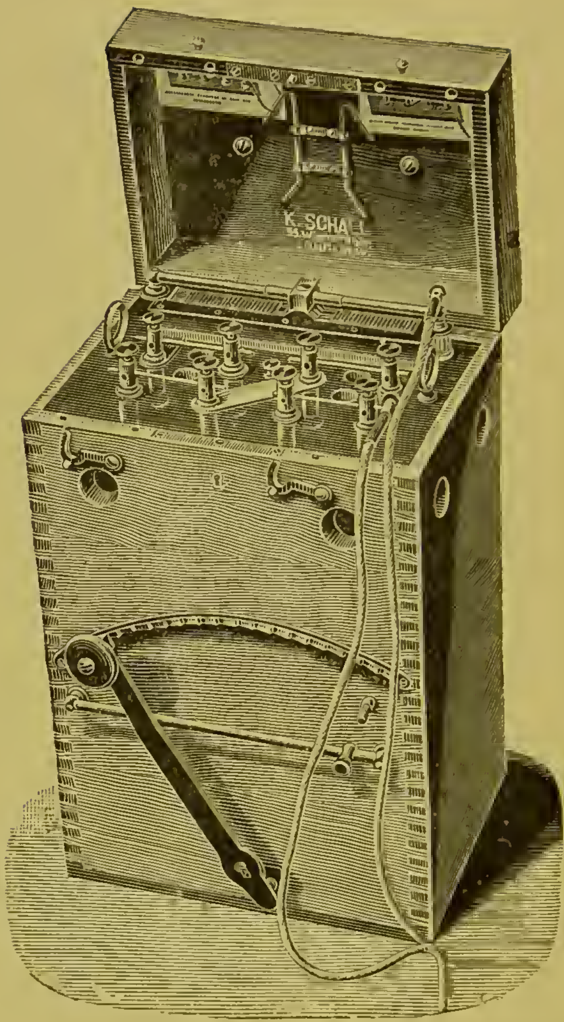


FIG. 93.—Bichromate battery for electric lamps and galvano-cautery.

By far the most convenient form of battery for cautery and lamp work is an accumulator. An accumulator or secondary battery gives a steady current, its internal

resistance is very small, its storage capacity is large, it can be recharged when exhausted from a dynamo or from the direct current mains (§ 69) and it will keep in good order for several years if given proper attention. With care in use (§ 59) they are perfectly trustworthy. They are heavy, but not more so than any

FIG. 94.—Accumulator for lamps and cauteries.

other cautery battery. The Electrical Power Storage Company prepare small accumulators for medical purposes. These will heat all ordinary cauteries well for the brief periods during which the cautery is required; if much heavy work is required to be done a larger size is better.

The most convenient outfit for cautery and surgical lamps is a four-celled accumulator. It may be fitted with a switch for rearranging the cells in two pairs in parallel, and can then be used either as a two-cell accumulator of double cells for cautery purposes, or as a four-celled one for lamps taking up to eight volts. There is no special advantage in this except for heavy

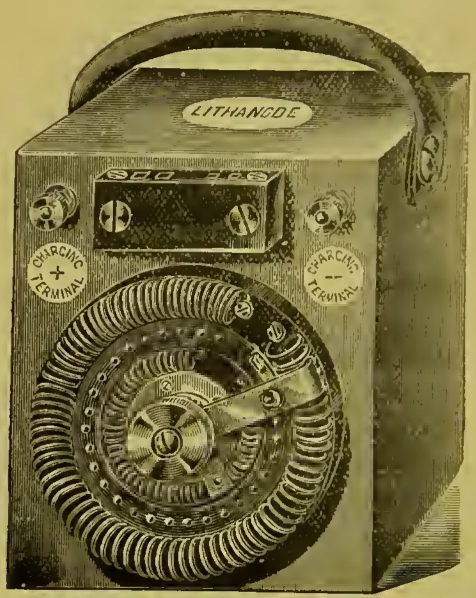


FIG. 95.—Accumulator for lamps and cauteries.

cautery work, and the extra connections are sometimes troublesome. Figure 95 shows such an apparatus, which is constructed for surgical purposes. It weighs fifteen pounds, and is provided with two resistances, one for lamp and one for cautery use. The connections are so arranged that the lamp resistance is in series with the lamp terminals and the cautery resistance with the

cautery terminals. It measures 7 × 4 × 5 inches, and is to be obtained from Mr. Leslie Miller, 93 Hatton Garden, E.C. The Lithanode Company also make a good accumulator battery for lamp and cautery work (fig. 95).

268. **Electric light mains.**—In § 66 the use of electric lighting mains for medical purposes was discussed. When they are to be employed for small surgical lamps or for cauteries, certain points are important, and will therefore now be considered. With the *alternate* current supply a transformer should always be used, and it should permit of adjustment to suit the exact pressure needed for the lamp or cautery to be used. This can be done by a proper make of transformer, or by means of an accessory resistance. There is no difficulty in obtaining what is required, as small transformers for light and cautery purposes are made specially (§ 70).

On *direct* current circuits the mains may be used to charge an accumulator and this can be subsequently used for the lamp or cautery. This has the advantage that the accumulator can be taken to a patient's house to be used. As this is necessary from time to time an accumulator must be had and then the fitting of an apparatus for use direct from the mains is not required, and the expense of it may, therefore, be saved with advantage. The charging is a simple matter, and has been already dealt with (§ 69). For small lamps an adjustable resistance direct on these mains is comparatively unobjectionable. When it is proposed to heat a cautery from the mains direct, the matter becomes much more difficult to carry out. A cautery requires ten ampères or more to bring it to redness, and a current of this magnitude is quite sufficient to maintain

an arc if from any cause the platinum of the cautery should break or fuse during its use. The unexpected establishment of an arc during cauterisation of a patient might have serious consequences.

The risk of such an accident can only be avoided by having two parallel circuits from the positive to the negative main, one to carry the cautery and the other to act as a bye-pass in case of accidental fusing or fracture of the cautery wire. No arc need then be feared, but the apparatus expends energy at the rate of about two-horse power while it is in action, and special main wires and fuses are required to carry the current. As each branch may have to carry upwards of ten

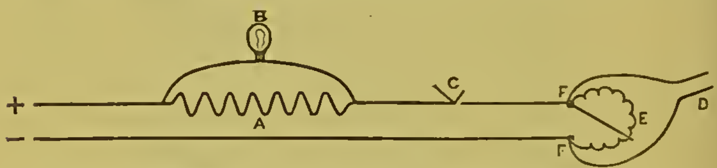


Fig. 96.—Arrangement of wires for cautery on continuous current mains.

ampères when the cautery is at work, they must be constructed in a substantial manner to stand that magnitude of current.

A properly designed apparatus for this purpose is in use at some of the London hospitals, and works well. Mr. Miller, who designed it, writes as follows:—"The apparatus we have fixed up has been in use for over a year and gives satisfaction. We see no other way of doing what is wanted, and for hospital use it is perhaps better than accumulators. A red lamp burns whenever the current flows, so that there is no excuse for wasting current."

A diagram of the connections is as follows:—A on the positive main represents a strongly made resistance of about five ohms. B is a red lamp. C switch. D

wires to cautery. E bye-pass, its exact resistance being varied by the moving arm, which is used as the regulator (fig. 96).

With this apparatus a current of about twenty ampères traverses the circuit when the switch is on. At FF the current divides, passing either through a resistance E, or through both E and the cautery D. The amount going by each route is adjusted by the moving arm, which can travel along E.

In this way the tendency to an arc is got rid of, and there is very much less sparking and burning at the contact in the handle of the cautery. Mr. Schall also supplies a similar apparatus.

269. **Conductors.**—It is important to use thick copper wire conductors for a cautery heated from a battery or an accumulator because the resistance of the whole circuit being very low, that of the conductors becomes an important fraction of it, and may determine whether the cautery will be properly heated or not.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Suppose that a cautery having a resistance of ·04 ohm and requiring a current of 20 ampères is to be heated, and that the battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being ·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to ·2 ohm. If proper leads are used, their resistance will be ·0014 ohm per metre. We will suppose each wire to be 1·5 metres in length, their total resistance will then be ·0042 ohm. The necessary resistance in circuit in this case (resistance of battery, of leads, and of cautery)

therefore amount to ·02 + ·0042 + ·04 = ·0642, or say ·065 ohm. This leaves a margin for faulty contacts and for rheostat of ·135 ohm, and the cautery would be adequately and easily heated. For the kind of rheostat used with cautery see figures 94 and 95.

But, now suppose that the leads are of a size having a resistance of ·04 ohm per metre. This will give a total resistance in circuit of ·02 + ·12 + ·04 = ·18 ohm, leaving a bare margin of ·02 ohm for faulty contacts. This would be insufficient, as there are several points of contact and a small degree of oxidation or tarnishing at any one of them would prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might destroy their insulation. These examples show the importance of using conducting wires with plenty of copper in them, and of keeping all contacts and binding screws scrupulously clean and bright. A rheostat must always be included in the circuit when a cautery is to be heated, if this precaution is neglected, there will be much trouble from over-heating and fusing of the platinum loops.

270. **Surgical lamps.**—Small incandescent lamps have been adapted to laryngoscopes, ophthalmoscopes,

FIG. 97.—Laryngoscope with electric lamp.

vaginal specula and other instruments (fig. 97 and 98). They are not used very universally, because in many cases the maintenance of the battery is troublesome, and because other sources of illumination are sufficient.

Lamps are also made to fix to an operator's head for giving a beam of light during operations. A very good small lamp is made by Beddoe, of Nine Elms Lane, S.W., and was described and figured in *British Medical Journal*, Dec., 1892, by Mr. Washington Isaacs. It throws a small parallel beam, and is nicely made. It weighs only half-an-ounce.

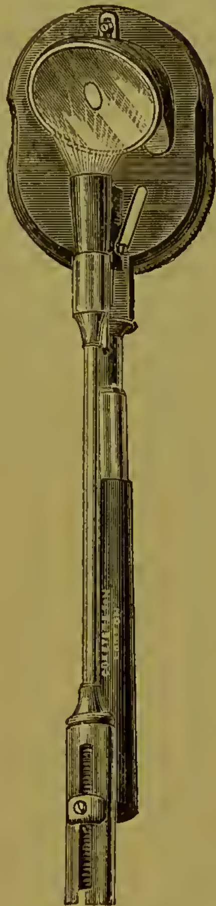


FIG. 98.—Ophthalmoscope with electric lamp.

These small lamps are of about one candle power and vary a good deal in their resistance (5-20 ohms), and therefore the electromotive force required to bring them to incandescence varies also. If the filament is slender, or if it is long, their resistance is high, if it is short or thick, their resistance is less high. A long slender filament may require eight or ten volts to light it properly, while a shorter one will glow with six volts. The rate of consumption of energy by an incandescent lamp is about four Watts per candle. Thus if a ten volt lamp absorbs ·4 of an ampère, a six volt lamp would require ·7 ampère to give the same light. When the current is supplied from a portable battery it is best to use the higher voltage lamp for the sake of the advantage of having to provide a smaller current, 400 milliampères, ·4 ampère being more within the range of a portable battery than 700 milliampères, and the battery will therefore run down less rapidly. On the other

hand a greater number of cells will be required to provide the higher voltage. It would be a convenience if all small surgical lamps were made for one and the same voltage. As the four cell accumulator of eight volts is the type of battery most generally useful lamps should be chosen as far as possible to incandesce brightly with this electromotive force.

Among primary batteries useful for lighting small lamps the bichromate cell is convenient if no means of recharging accumulators are available. Dry cells may be used for this purpose, but do not keep well nor last long if used much for lamps. Six dry cells fitted in a plain oak box are supplied by Mr. Schall with a simple form of rheostat, and they may be trusted for a fair number of examinations. It should be borne in mind that dry cells gradually fail as they get old, whether they be used or not. From three to six months may be taken as the duration of usefulness with dry cells.

If accumulators are used, small ones may be had for the sake of portability. Small accumulators are put up by several electrical instrument makers and serve well for surgical lamps (see fig. 15 and 16). The small sizes naturally require recharging more often than the large ones, but this is not an objection, because all accumulators are better for being recharged at least once a month, and the capacity of the small cells is sufficient for lighting a cystoscope or similar lamp for several hours. If the small accumulators can be recharged at home from the mains without trouble they are extremely convenient, but this convenience is mainly lost if they have to be sent away every time to be recharged.

271. **Rheostats.**—We have already said that the lamps vary a good deal in their resistance, and a

regulating resistance in the circuit is necessary for compensating for these variations, as without it some lamps would be overheated and would quickly be destroyed. Rheostats of convenient size are supplied with many of the types of portable accumulator now in the market. The resistance required for regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well made lamp the resistance is easily made of a few turns of fine German silver wire. Rheostats are equally important for cauteries, but there they have to carry large currents and must be made of thick wire; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit.

272. **The cystoscope.**—This is an instrument for examining the mucous membrane of the bladder, and it is perhaps the most important and useful of all the electric lamp instruments, because it affords information of the greatest value which cannot be obtained without it. The cystoscope (figs. 99 and 100) consists of a beaked sound, in which there is a telescopic arrangement by which the surface of the bladder is viewed through a small window of rock crystal. A lamp *L* is enclosed in the beak of the instrument and throws its light through another window *CF* (fig. 100), upon that part of the bladder wall which is in the field of view of the telescope. *B* is a screw for making contact, the wires are fastened at *CD* (fig. 99) For examining the upper part of the bladder a separate instrument with a small reflecting prism is used. A certain amount of practice is required to use the cystoscope properly, and to recognise the appearances of the mucous membrane

of the bladder in health and in its various morbid

Fig. 99.—Cystoscope.

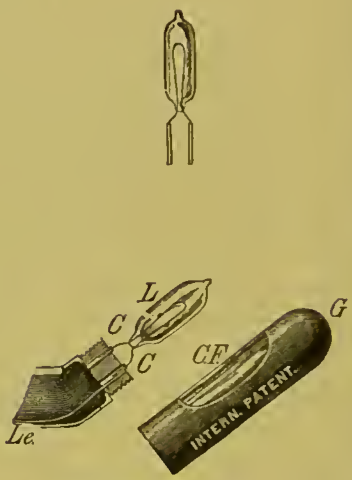


Fig. 100.—Arrangement of lamp in cystoscope.
L. Lamp. *CC.* Attachment to instrument. *CF.* Window in cap of instrument.

conditions. With the dummy bladder (fig. 101) the necessary skill can be quickly picked up. For a full

account of the instrument and mode of using it, see Mr. Hurry Fenwick's book on "The Electrical Illumination of the Bladder and the Urethra."* An anæsthetic is not absolutely necessary for a cystoscopic examination, but it is more convenient to employ one, though cocaine may be made to do. The bladder must

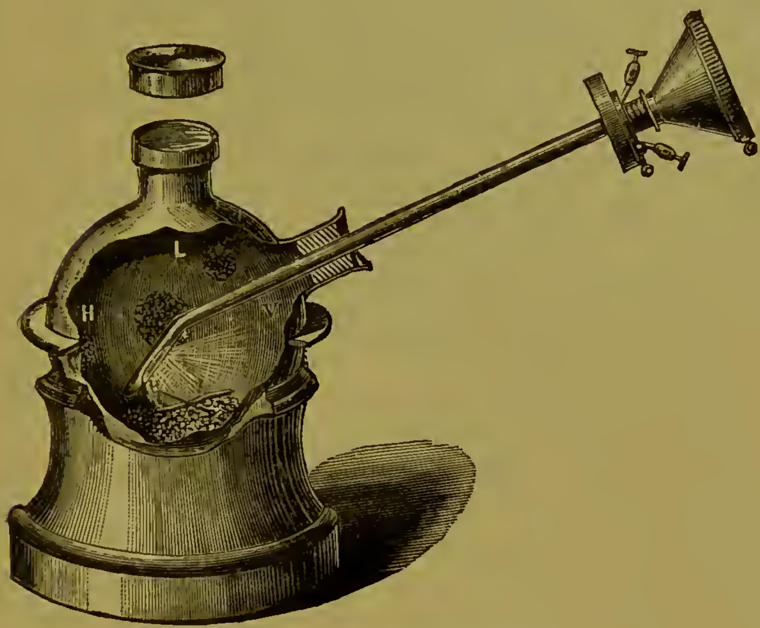


FIG. 101.—Cystoscope and dummy.

contain six or eight ounces of clear urine or clear water if a proper view of its walls is to be obtained.

If the fluid present be even slightly turbid, the view is very much obscured; and the bladder must be washed out with warm boracic lotion until the fluid which returns is absolutely clear. If too little fluid be present in the bladder, the beak of the instrument with

* London, J. & A. Churchill.

the lamp is likely to become buried in the folds of the mucous membrane, and there will be no light. Moreover, in that case the mucous membrane may be burned.

When the bladder contains eight ounces of clear fluid the end of the cystoscope lies free in the cavity, and the lamp is kept cool by the circulation of the water. The instrument must be pushed well home into the bladder and kept there; if it be allowed to work out at all, the beak may become engaged in the prostate, and then nothing will be seen and the prostate may be burned. The heat of the lamp is unimportant when it is surrounded by a volume of water, but when the lamp lies close against the mucous membrane there is no circulation of fluid round it, and it gradually grows hot and will burn if held too long in one place.

273. **The panelectroscope.**—An universal lighting apparatus has been introduced by Leiter, of Vienna, under this name. It consists of a lantern with a handle and mirror; the light from a small incandescent lamp is projected by the mirror along a tube, which is inserted into the part to be examined. Tubes of various sizes are adapted to the instrument. It is especially useful for endoscopy of the urethra, but is also arranged for examining the ear, the pharynx, the stomach, &c. For a full account of the method of using it for examining the urethra, and of the appearances of the different morbid states, see Mr. Hurry Fenwick's book already quoted in the last paragraph.

Another convenient lamp for abdominal surgery is shown in fig. 103. It is designed in such a way as to be kept clean and aseptic without any difficulty. It may be left in the antiseptic solution until required for use. The attachment to the leads is by a double

socket [fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead which passes down the centre.

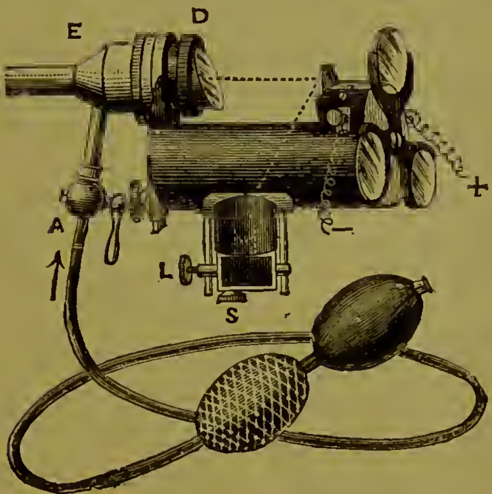


FIG. 102.—Panelectroscope (handle not shown).

The enclosing tube of glass prevents any burning of the tissues with which it might come in contact during an operation.

The exploration of the antrum of Highmore by means

FIG. 103.—Lamp for abdominal operations.

of a lamp placed in the mouth, has excited a considerable amount of interest since the publication by Heryng*

* *Berlin. Klin. Wochens.*, No. 25, Sept. 2, 1889. "L'éclairage électrique de l'antre de Highmore dans le cas d'empyème." See also "De l'empyème latent de l'antre de Highmore; Dr. Jeanty." Bordeaux, 1891, Feret et fils.

of his paper on the subject. The patient must be in a perfectly darkened room, the lamp is introduced into his mouth, and the lips are closed over its stem; when the current is then turned on the face becomes lighted up by a red glow. If one antrum contain pus a dark shadow is seen on the corresponding side, which is most perceptible just below the eye. A properly arranged lamp is made for the purpose by Mr. Schall. It should have an illuminating power of three or four candles.

Fig. 104.—Electro-magnet.

The same method of trans-illumination has been employed for detecting deep-seated pus in other parts of the body; it has even been said that by means of a light in the bladder the contours of the abdominal viscera have been traced out. The diffusion of the light through the tissues, however, does not give much in the way of detail.

274. **The electro-magnet.**—In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, especially from the eye. Permanent magnets can also be used. Mr. Simeon Snell* has made large use of the electro-magnet, and has had great success with it. If

* "The Electro-magnet in Ophthalmic Surgery," and *Brit. Med. Jour.*, November, 1883.

the particle of iron be very small, or if it be fixed at all firmly in the tissues a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet introduced through a small incision.

One form of the instrument is figured here (fig. 104), several interchangeable pole pieces of different shapes and sizes are generally supplied, the most suitable one for each case can be screwed on at A as required. A few cells of any battery will suffice to excite the electro-magnet. It is sometimes useful to magnetise it by closing the current circuit after it has been placed in position near to the piece of iron. This is done in the instrument here figured by pressing down the small projecting slip of metal seen on the surface of the coils. The sudden magnetization then tends to jerk the piece of metal away from its bed. In the same way an electro-magnet excited by an alternating current has been found useful. The alternate magnetisation and de-magnetisation set the steel particle vibrating, and promote its dislodgment. In firmer tissues it is not always possible to extract it by an electro-magnet, for naturally it cannot hold the particle as firmly as it would be held by any kind of forceps. A large number of communications on the electro-magnet in surgery will be found in the medical journals

CHAPTER XVI.

The Röntgen Rays.*

The Crookes' tube. The sources of electricity. The static machine. Management of coils. Screen work. Photography. Localisation of foreign bodies. Diseases of the heart and lungs.

275. The discovery of Röntgen or X rays followed upon the work of Lenard, who, experimenting with Crookes' tubes, had found that he was able to obtain manifestations outside the tube. Until his time the attention of observers had been so fixed upon the phenomena taking place inside the tube that effects outside the tube had not been looked for. Lenard found that a Crookes' tube, when excited, emitted radiations which could be recognised in the open air outside and around the tube, and that these radiations had the power of exciting phosphorescence in suitable bodies, and of acting upon sensitive photographic plates; and, in particular, that this action on photographic plates could take place through the sides of a cardboard box, which had little effect in stopping the "kathode" rays. With this to work upon, Professor Röntgen drew the important deduction that a Crookes' tube could be made to

* This chapter is not intended to give more than an outline of the methods and principles concerned in X ray work. The subject is too large to be dealt with in a few pages. Those who wish to make a study of the subject will find an admirable book upon it in "The Röntgen Rays in Medical Work," by David Walsh, 2nd edition London, 1899. Bailliere, Tindall and Cox.

give out rays which penetrated opaque bodies in proportion to their density, and could be made to throw shadows on a photographic plate, which when developed would give an image showing any inequalities of density in the object photographed. It was a natural step from this to make a photograph of the hand showing the bones: and upon this, again, the very important development of X ray work in surgical and medical practice has been erected. Professor Röntgen's work was much more than this, for he distinguished between Lenard's "kathode rays" and his own or X rays and indeed worked out the whole of his subject so thoroughly as to leave but little for subsequent investigators to discover.

The essential parts for the production of X rays are two in number; first, a Crookes' tube, suitably modified; and, secondly, an electrical apparatus capable of supplying currents at the necessary electro-motive force to excite the tube to action.

276. **The tube.**—A Crookes' tube is a vacuum tube in which the exhaustion of the air has been pushed to its utmost limits. It differs from an ordinary vacuum tube in the phenomena which it exhibits when electrically excited. Whereas an ordinary vacuum tube appears filled with glowing gas during the discharge of electricity through it, the Crookes' tube shows little or none of this appearance; while instead of it a peculiar phosphorescence of the walls of the tube, previously hardly apparent, is the most conspicuous feature. The vacuum in a Crookes' tube is about one-millionth of the pressure of the atmosphere. The phosphorescence in such a tube is caused by a bombardment of its walls by gaseous molecules propelled with enormous velocity from the kathode. And it was shown by Crookes that these molecules are propelled in straight

lines from the surface or surfaces of the cathode, and continue to travel in straight lines until they strike an obstacle, such as the walls of the tube itself, or of any body intentionally enclosed in the body of the tube and in the path of their movements. The X rays are produced when the bombardment strikes the solid object. Any tube exhibiting this phosphorescence of its walls is emitting X rays from the phosphorescent parts and the earliest tubes used in X ray work were of this kind. The objection to them was that X rays were emitted from a large portion of their surface, and therefore did not give pictures so sharp in focus, as if the rays had been emitted from a small surface. The greatest improvement in the construction of the special Crookes' tube for X ray work was effected by Mr. Jackson, of King's College, London, who contrived a tube with a piece of platinum fixed in such a position as to receive the concentrated bombardment from the kathode. The X rays in his form of tube are emitted from a small portion of the surface of the platinum instead of being emitted from a large portion of the glass wall of the tube. The kathode usually takes the form of a cup-shaped disc of aluminium; and the platinum target or anti-cathode devised by Mr. Jackson is placed nearly at the focus of the cathode. Owing to the cup-shape of the cathode, the bombardment converges to a point at or near the surface of the anti-kathode. The object of the high vacuum is to diminish the number of molecules of gas remaining in the tube to such a degree that those which are left shall be free to move in straight lines, without obstruction or retardation from collisions with other molecules. Thus, the higher the vacuum the more freely can the repelled molecules travel until they strike the anti-kathode. In tubes of low vacuum their

movement would be arrested before they could travel the required distance. The figure shows a form of the Jackson tube which is now most widely used. In it one may see the cup-shaped kathode, the obliquely placed target or anti-kathode of platinum, and a third terminal which is usually connected to the anti-kathode outside the tube, and which acts as a regulator, making the behaviour of the tube more constant. The probable action of the third pole is to serve as a means of relieving the molecules of their electrical charges, thus setting them free to return to the cathode, whence they are

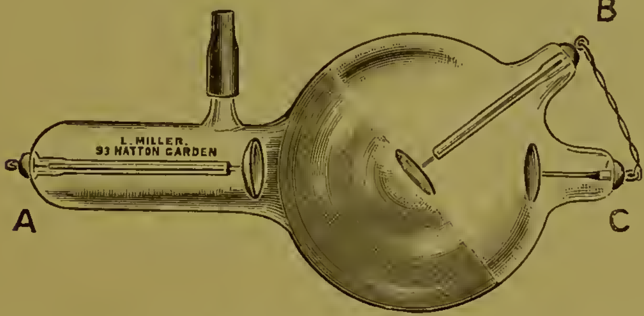


FIG. 105.—X ray tube. A. Kathode. B. Anti-kathode. C. Anode or third terminal.

again repelled. It has been noticed that during use a vacuum tube becomes gradually more and more difficult to excite; and many tubes have had to be returned to the maker to correct this fault, owing to their vacuum having become so high as to resist the full power of the coil used for exciting them. Tubes with a third pole increase in resistance much more slowly. The actual degree of vacuum which is best in a tube will depend upon the electromotive force which is available for exciting it. Thus, a tube which is too high for a coil of medium size will serve admirably for another of greater

strength. There are, therefore, fairly wide limits of vacuum within which X ray effects can be produced. The higher the vacuum in the tube, the stronger is the electromotive force necessary to work it, but the better is the quality of the X ray radiance emitted. Or rather, one may say, the greater is the power of penetration of the X ray radiance emitted. The words "soft" and "hard" are commonly used to designate tubes of lower and of higher resistance respectively. Thus, we may say that a tube which is soft when new will gradually become harder and harder with use, and will, therefore, become more suitable for photographing the thicker parts of the body and less suitable for photographing the thin ones. If too "hard" its rays may have too high a penetration, and will then traverse bones almost as freely as soft tissues and will give a photograph in which the contrasts between the bones and the soft tissues are insufficiently marked. Dr. Mackenzie Davidson has introduced a further improvement into the X ray tube. The improvement consists in using a piece of solid osmium to receive the bombardment from the cathode. Platinum is too soft a metal to stand the full effects of a sustained molecular bombardment concentrated upon one point on its surface; and on this account in ordinary X ray tubes the platinum anti-cathode is intentionally placed at a little distance beyond the actual focus of the bombardment. When osmium is used, its hardness and infusibility make it possible to place it in the exact focus of the discharge. The X rays emitted by such a tube are therefore emitted from a smaller radiant point, and throw sharper images than the ordinary tubes.

277. **The source of electricity.**—Very high electromotive forces are required to excite an X ray tube,

and the instruments in use for obtaining the high electromotive forces needed are (1) the induction coil, (2) the statical machine, (3) the Tesla coil. Of these the induction coil is the most generally useful, and most of the X ray work done in this country is performed by means of coils. The statical machine also has advantages which will be considered immediately, but it has the one great disadvantage of not being portable except in the smaller sizes, and these have not yet shown themselves equal to the coil. It is therefore not possible to use it for cases requiring the application of X rays at the bed-side. The Tesla coil affords a convenient means of obtaining currents of high potential, wherever alternating electric light mains can be tapped, but it has the disadvantage of breaking the tubes very rapidly. It is also objected to it that it is bad because it gives an alternating current as compared with the unidirectional current of the induction coil. This, however, is not the real objection to it. The real objection is that its discharges are high frequency discharges, and high frequency discharges behave in a very peculiar manner inside a vacuum tube. Strange to say, it is very difficult to confine them to the leading-in wire so as to deliver them where wanted at the surface of the kathode. They seem to prefer to escape into the vacuum tube from the stem or support of the cathode, as though anxious to pass from the metallic conductor into the gaseous one. If the stem be protected by a glass tube, as is usual, they will quickly puncture this, and opposite the point at which they so puncture the glass stem, they quickly heat the wall of the tube and cause it to crack. On this account the use of the Tesla coil is rendered so costly and troublesome that it is now almost totally neglected in X ray

work. Induction coils are generally classified in terms of the length of the spark which they are capable of giving. Thus a six-inch coil is one which can give a spark of six inches in length. The proper size for good practical X ray work is a ten-inch or a twelve-inch coil. Good work may be done with a six-inch coil, and X ray photographs may be taken with a coil giving only a two-inch spark. But in practical work it is found that the more powerful the coil the better will be the pictures, and the shorter will be the necessary period of the exposure. From what has been said of the difference between soft and hard tubes, it will follow that a tube which is too hard to be excited at all by a four-inch coil, may behave as a good tube for a ten-inch or twelve-inch coil.

With a twelve-inch coil the tubes remain longer in condition than with smaller coils. The increase of resistance of the tube or its "hardness" which comes from use comes more slowly with the larger coils. It appears as though the electrical stresses set up at these high electromotive forces are sufficient to break down the resistance of almost any tube; certainly, since the general use of twelve-inch rather than six-inch coils the need for re-exhaustion of tubes seems to be very considerably diminished. At St. Bartholomew's Hospital I have noticed this in a very marked way. At present we hardly ever find that tubes have become too high for work. When we used a six-inch coil our tubes aged much more quickly.

The statical machine.—The special advantages of the statical machine consist in its simplicity. Whereas a coil requires accumulators to drive it—and the recharging of these accumulators may be a matter of great difficulty in remote or country places—the statical

machine is a self-contained electrical apparatus capable of generating the necessary electromotive force by itself whenever its handle is turned. It also gives a steady radiation with X ray tubes, which is much less tiring to the eye with screen work than the flickering light given by the interrupted discharges of the induction coil. In fact, for screen work the statical machine is admirable. For photography it is as good as the induction coil, though perhaps no better, and wherever an apparatus is required which need not be transported to the bed-side of the patient, the statical machine has much to recommend it. It has been said that with the static machine longer exposures are needed than is the case with large coils, but the statement needs confirmation.

278. **The coil.**—The working of the large coils used in X ray work requires a little experience, particularly in the management of the contact breaker. The contact breakers of large coils may either be the ordinary vibrating hammer, like those used in small medical induction coils, or the interruptions in the primary circuit may be produced by some mechanical device separate from the coil, or by the peculiar electrolytic arrangement known as the Wehnelt interrupter. The ordinary hammer answers very well for coils up to six inches; even with ten and twelve inch coils a large amount of the work done with X rays is carried on with the vibrating hammer fitted with a "tension screw" for purposes of regulation. If a few experiments are made with a long spark induction coil, it will soon be found that small adjustments of the tension screw of the contact breaker produce very great effects in the length of spark which the apparatus can be made to give out. Thus, with the contact breaker spring quite loose, a

six-inch coil will only give sparks of one or two inches, and the sparks can be made longer and longer by

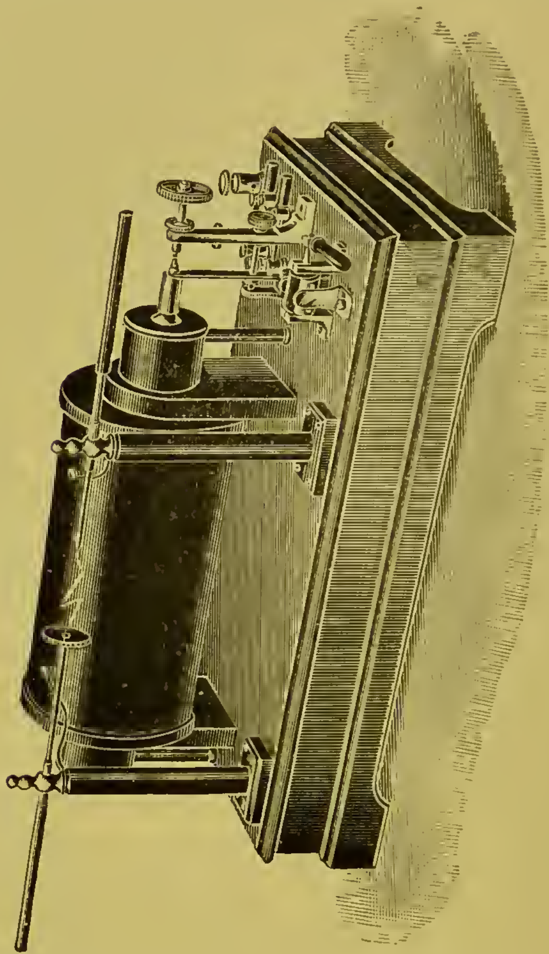


FIG. 106.—Large induction coil.

increasing the tension of the screw of the contact breaker. The management of the contact breaker therefore consists in adjusting the tension of its spring

to suit the tube which is being used and the part which is being photographed. For thick portions of the body and hard tubes it may be advantageous to screw up the contact breaker so tightly that the full strength of the battery is necessary to make it work. Under these conditions the primary current is only broken when the full current is flowing in the primary and the full magnetising effect upon the iron core is developed. A sudden break of current at this moment gives the maximum effect of which the coil is capable. When working with a tightened tension spring it is necessary to stand by the apparatus while it is at work lest the platinum points of the vibrator may stick and the rush of current which follows may damage either the accumulators or the coil. It is also necessary to take care of the platinum contacts of the contact-breaker. They burn away gradually and their surfaces become uneven and need to be filed from time to time, to give them flat, smooth, clean surfaces, if the coil is to work satisfactorily. New platinum points must be fitted when the old ones are worn away.

When the coil has been made to work satisfactorily the tube may be connected to it and the current turned on. The tube is held in a wooden clamp of suitable size and shape, many patterns of tube holder are made. When set in action, the phosphorescence of the glass is the indication which shows whether the tube is working properly, and the correct direction of the discharge through the tube may be obtained by means of a commutator in the primary circuit of the coil. When the kathode of the tube is properly attached to the negative pole of the coil, the phosphorescence will occupy one hemisphere only of the tube, the hemisphere which fronts the face of the anti-kathode which is turned

towards the kathode. If the connections are wrong, the phosphorescence inside the tube is not thus sharply confined to its proper part, but is irregular and ill-defined on all parts of the tube. If the room is darkened, a phosphorescent screen held in front of the anti-kathode will shine brightly, and the hand placed between it and the tube will throw a shadow in which the bones are quite easy to perceive. The phosphorescent screens are usually ten inches by eight inches in size. Larger or smaller ones may also be used. But the small screen is often to be preferred to a larger one, because with a screen larger than the part under scrutiny the eye becomes dazzled by the phosphorescence of adjoining parts. Various phosphorescent bodies have been tried in the manufacture of screens, but the material which has finally asserted its superiority is the platino-cyanide of barium. This phosphoresces with a greenish-yellow light. A little work in a dark room with a phosphorescent screen can be made extremely instructive. In this way one can learn how easy it is to produce distorted impressions when the object viewed is not in a plane with the surface of the screen. And from this one recognises how important it is in taking X ray photographs to arrange the careful adjustment of the tube, the patient, and the photographic plate, in their relations to each other.

279. **X ray photographs.**—It has already been mentioned that Lenard early discovered the effect of X ray radiations upon photographic plates, even when the rays had passed through the sides of a cardboard box to reach the plates. In X ray practice photographs of the bones are taken by means of photographic plates enclosed in light tight envelopes of paper. The plate is

usually enclosed in a yellow envelope, which again is enclosed in a black envelope. By this means the action of ordinary light upon the plate is prevented, but the passage of X rays to the plate remains quite possible. The plate enclosed in this way is laid upon a table or other support, and the limb is placed upon it. The tube is then adjusted at a distance of a foot or eighteen inches above the limb, and the coil is set in action. The hand or limb must be kept quite still during the exposure, which may last from a few seconds up to many minutes, according to the efficiency of the apparatus and the density and thickness of the part to be photographed. As soon as the exposure is concluded, the coil is turned off, and the plate, still enclosed in its envelopes, is removed to a dark room for development, and development is carried out in the ordinary way, as in simple photography. Envelopes of the proper kind can be obtained from the makers of photographic materials. The photographic plates may be of any make or speed. Various kinds have been specially recommended by different writers, but there does not seem to be any conspicuous difference between one kind and another. It is better to choose one kind of plate and adhere to it, because in this way the peculiarities of the plate are the more quickly learned. Cadett's "Lightning" plates are good. In putting the plate into the envelopes a little care is needed in order that the film or sensitive side may face in the right direction. The plan is to put in the plate with its film side away from the flap or opening, and then to put the yellow envelope into the black envelope, with the plain sides in apposition. The side with the flap or opening of the envelope is then the side of the glass or non-sensitive side; the other is the side of the film which must face the X rays. The operation must

of course be done in a dark room. As with choice of plate, so with choice of developers; it is best to make use of those with which one is best acquainted. A very simple and convenient developer is Rodinal. It has the advantages of easy preparation, of effective action, and it does not stain the fingers. As with X ray work the exposures are seldom very far removed from what may be called the minimum normal exposure, a simple developer of maximum strength can usually be employed without the risk of spoiling the plate in the process of developing, and whenever the exposure and the development are both carried out by the same person it is found that a time is soon reached when one may very closely assimilate time of exposure and strength of developer so as to give the best results. The question of skilful development belongs rather to photography than to medical electricity, and in many cases the plates are sent for development to professional photographers. But wherever the best results are desired it is recommended that development should be performed by the one who has exposed the plate. An over exposed plate may be known by a fulness of detail in the whole plate with a general blackness of the whole subject if development is fully carried out, while an under exposed plate shows very great contrasts with absence of detail in the shadows of the more opaque parts of the subject. An over exposed plate which has been developed for too short a time will be thin and lacking in density all over, although it may show details of structure in all parts of the subject. When many photographs have to be done, the time lost during prolonged exposures may become a serious item. But in ordinary private practice, where it is not likely that many plates will require to be done at the same

time, it is better to give a full time exposure to the plate, in order to get all the detail which is possible. The question of the proper time to give to the different parts of the body is one which only practice can settle, for it depends upon the size of the coil, the energy with which it is driven, the quality of the tube that is being used for it, and the distance between the tube and the photographic plate. The nearer the tube is to the plate, the shorter need the exposure be. But, on the other hand, distortion is more evident in plates exposed with the tube very close than it is in plates exposed with a tube which is distant. For fine work, then, one will be content to have the tube at a distance of eighteen inches or two feet from the object, and to give a slightly longer exposure. The approximate times for a twelve inch coil may be set down somewhat as follows:—For the hand and wrist, fifteen to thirty seconds; forearm, upper arm and elbow, one to two minutes; shoulder and thorax, three to five minutes; knee and thigh the same; pelvis and abdomen up to six minutes. With smaller coils longer exposures will be necessary. But it must not be thought that a long exposure with a small coil will give equivalent results to those obtained from a short exposure with a large coil. The larger the coil the quicker may be the exposure, but in addition the sharper would be the picture. Sometimes one is annoyed by finding on development a general blurring and blackening of the photographic plate which otherwise shows little or no detail. This is a trouble met with, especially in the photography of thick parts of the body, like the abdomen and pelvis, with coils of poor power and long exposures. In photographing the trunk, then, it is best to make use of large coils, and to shorten the exposure to the minimum which will serve to give

an image of the part desired. These parts, as a general rule, are the vertebræ, the kidneys (for renal stone), the pelvis and hip joints. All these subjects are extremely difficult to do nicely, even with the best coils, and long practice is needed in gauging the performance of the tube, and in adjusting the time of exposure to the bulk of the subject. When a tube has been found to have reached the degree of vacuum which just suits the coil used for these difficult parts, it is well to treasure such a tube, and to keep it only for these special subjects, using some other not so good for the easier parts, like the hands and feet, the forearms and legs. The tube should always be fixed so that the rays can fall perpendicularly from it upon the limb and the plate. Obliquity in the position of either the plate or the limb is likely to give that distortion which has been referred to in a preceding paragraph. A little study of these distortions as seen upon a phosphorescent screen held obliquely is the best method of learning what effects these distortions produce, and what is the best way to avoid them.

280. **The localisation of foreign bodies.**—A difficulty which early showed itself in the localisation of foreign bodies by means of X ray photographs is the difficulty in determining the plane in the limb in which the foreign body is placed. How deep down is it? is a question which will constantly be asked before any procedure for removal can be considered. Various plans for localisation have been devised. In this country the methods of Mr. Mackenzie Davidson are in almost universal use.

The principle upon which Mr. Mackenzie Davidson's localiser depends is the displacement of the image of the foreign body on the photographic plate which is

produced by a displacement in the position of the tube. Two exposures are given upon the same plate, the limb being perfectly still all the time, and a known displacement is given to the tube before the second exposure. Then, the distance of the tube from the plate being known, and the amount of the lateral displacement of the tube being known, a diagram can be constructed taking in these two factors and the measured displacement of the body as seen by its two images on the photographic plate; and from this, by a simple calculation, the distance of the foreign body from the surface of the photographic plate can be deduced. In practice the calculations are very much simplified by the use of the apparatus designed by Mr. Davidson. Two fine threads, starting from two points, which represent the two positions of the focus tube, are brought down to the two images of the foreign body which are seen upon the photographic negative. The point where the two threads cross in the air above the negative is the point at which the foreign body is situated. That, indeed, is the only point at which it can be, in order to throw the two images which it has thrown. By means of simple measuring scales supplied with the apparatus, the height or the depth of the body from the surface with which the plate was in contact is readily calculated. Its distance from a given point in the photograph, which is usually a line marked upon the surface of the patient at the time of the photograph, can also be measured quite easily.

In very many cases the position of the foreign body can be estimated with considerable accuracy by the method of taking two photographs and viewing them in a stereoscope. For this the two photographs are taken not on the same plate, but on two separate plates

but the tube is displaced for the second exposure, just as in the process just described. From the two negatives two prints are prepared, and these are viewed by means of a reflecting stereoscope. The binocular image thus obtained has a most remarkable effect in reconstructing to the observer's eye the entire part of the body in which the foreign body lies; and it appears to stand out with all its roundness and thickness, and the foreign body also can be seen as it lies in the depth of the tissue in such a way as to give a very real picture of its actual position and depth from the surface. One or other of these methods, the method of measurement or the method of stereoscopic view can be adopted. The essential part for success in either of them is the exact adjustment and the exact measurement of the various distances; namely, the distance of the tube from the plate, the distance through which the tube is displaced for the taking of the second photograph. The apparatus devised by Mackenzie Davidson renders all these details easy by means of dividing scales and sliding tube holders.

281. **Applications to diseases of the chest.**—Although the detection and localisation of foreign bodies in the tissues is one of the most obvious of the applications of X ray work in surgery, yet it is not by any means the only one. More important is the examination of fractures, dislocations, and other changes in connection with the bony skeleton. And perhaps more important still in the future may be the detection of changes in the soft tissues. The shadows cast upon photographic plates by X rays depend upon the different densities of the objects photographed. Thus, whereas in a photograph of a limb the contrast is between bone and the soft tissues, the detail being visible in the bone and

the detail in the soft tissues being practically non-existent, yet in cases like the thorax, where the more dense heart is surrounded by the less dense lung, it becomes possible to obtain valuable photographs of the heart and of the lungs respectively. Changes in the size and shape of the heart, or of the aorta (aneurysm) can therefore be detected. In the lungs any changes tending to consolidation of the naturally spongy tissue can be detected for the same reason. Tumours, consolidations—pneumonic and phthisical—and effusions into the pleura are all easily recognised in good X ray photographs of those parts. Its application to the study of early phthisis is perhaps one of the most promising of all the applications of X ray work to medicine. The chief work done in this country in that direction has been done in the electrical department of St. Bartholomew's Hospital by Dr. Hugh Walsham.* He has shown again and again that small tubercular consolidations which cannot be detected by the stethoscope can be easily and certainly revealed by X ray work. And the importance of this, when the early diagnosis of phthisis is in question, is enormous. This field, although at present hardly begun, is likely to progress considerably when it has been studied further. In the photographs of the chest, as in those of the limbs, the combination of two pictures by means of the stereoscope is often of the greatest value in enabling one to form an estimate of the actual position and depth from the surface of any tubercular consolidation or tubercular cavity; for a cavity can be revealed by X rays just as well as a consolidation, although for the opposite reason, namely, that whereas a consolidation is denser than the normal lung, a cavity is less dense.

* *Archives of the Röntgen Ray*, May, 1900.

282. **Therapeutic uses of X rays.**—In addition to the photographic application of X rays for purposes of diagnosis, we have also to consider the therapeutic applications of the X rays themselves. Following upon the discovery that prolonged exposure to X rays produced changes in the skin—the X ray burn—it has been found that careful graduation of this effect can be made to exercise a curative action upon certain skin diseases, and particularly upon lupus. The whole field of the application of X rays to diseases of the skin is one which has not yet greatly been worked at. In this country Miss Sharpe (see *Archives of the Röntgen Ray*) has detailed a number of experiences of her own of this kind. Abroad, the removal of superfluous hairs from the skin by exposure to the X rays has been elaborated by Professor Schiff, of Vienna, who has succeeded in so adjusting the degree of exposure as to cause a permanent shedding of the hairs without the destruction of the skin itself. The matter is one requiring great nicety of adjustment. The effect is one probably of damage to the superficial nerve endings, with consequent trophic changes which may affect only the hair bulbs, either temporarily or permanently, or may exercise so severe an action as to cause permanent destruction of the skin itself. The difficulty lies only in the adjustment of it. Whether these skin effects—the X ray burn and the others—are really due to the direct effect of the X rays themselves or not, is a little uncertain. As X ray tubes have been improved, the number of recorded cases of X ray burn have decreased rather than increased. In the early days the conditions were tubes of comparatively low vacuum, long exposures, and tubes placed close to the patient. Those seem to be the conditions which favour the X

ray burn ; and it has been believed that the effect on the skin is not so much an action of the X rays themselves, as of the electrical brush discharge taking place from the surface of the tube to the surface of the skin.

APPENDIX.

1. *Lists of Towns and Districts with Continuous Current Supply.*

PROVINCIAL.

Aberdeen
Alderley and Wilmslow
Ashton-under-Lyne
Barrow-in-Furness
Belfast
Bilston
Birkenhead
Birmingham
Blackburn
Bolton
Bootle
Bradford
Bridlington
Brighouse
Brighton
Bromley (Kent)
Buckingham
Burnley
Bury
Canterbury
Carlisle
Chester
Chislehurst
Colchester
Cork
Darwen (Lancs.)
Dewsbury
Dundee
Edinburgh
Folkestone
Fort William
Galway
Glasgow
Gorseinon
Govan
Greenock
Guildford
Harrow-on-the-Hill
Hereford
High Wycombe
Hove
Hull
Ingleton
Kelvinside

Keynsham
King's Lynn
Lancaster
Leamington
Leith
Leyton
Lincoln
Liverpool
Llandudno
Londonderry
Maerdy (Glamorganshire)
Manchester
Mevagissey
Middleton
Morecambe
Nelson
Newington
Northampton
Northwich
Norwich
Nottingham
Ogmore Valley
Oldham
Oswestry
Oxford
Pontypool
Preston
Richmond (Surrey)
Rottingdean
Salisbury
St. Austell
Shrewsbury
Southampton
Stafford
Stockport
Stockton
Sunderland
Treeton
Ventnor
Walsall
Whitehaven
Winchester
Windsor
Wolverhampton.

LONDON.

Barking
Charing Cross and Strand Co.
Chelsea Co.
Kensington and Knightsbridge Co.
Notting Hill Co.
Smithfield Markets Co.
St. James' and Pall Mall Co.
Shoreditch
Strand
St. Pancras (Vestry)
Sydenham
Westminster Co.
Whitechapel
Woolwich.

2. *List of Towns and Districts with Alternating Current Supply. The periodicity expresses the number of complete cycles (§ 71) of alternation per second.*

PROVINCIAL.

	Periodicity		Periodicity
Aberystwith	100	Eccles	50
Altrincham	80	Edinburgh (in part)	50
Ayr	60	Exeter	100
Bath	100	Fareham	125
Bedford	60	Halifax	80
Blackpool	83	Hanley	100
Bolton	83	Harrogate	50
Bournemouth	100	Hastings	100
Bray (Ireland)	60	Huddersfield	100
Bristol	93	Keswick	100
Burton-on-Trent	75	Killarney	100
Cambridge	90	Kingston-on-Thames	77
Cardiff	40	Larne	100
Carlow	100	Leeds	83
Chagford	100	Leicester	50
Chatham	100	Lynton and Lynmouth	83, 100
Cheltenham	93	Monmouth	60
Coatbridge	100	Morley (Yorks.)	60
Coventry	87	Newcastle-on-Tyne	80
Croydon	60	Newport	87
Derby	40	Paisley	50
Dover	100	Plymouth	50
Dublin	83	Portsmouth	100
Ealing	40	Prescot District	100
Eastbourne	83	Reading	67

	Periodicity		Periodicity
Redditch	66	Torquay	50
Rugby	100	Tunbridge Wells	67
St. Helens	60	Wakefield	60
Salford	75	Wallasey	50
Scarborough	80	Watford	100
Sheffield	100	West Ham	50
Southport	50	Woking	100
South Shields	50	Worcester	100
Taunton	60	Yarmouth	83

LONDON.

City of London	100	London Electric Co.	83
Hammersmith	50	Metropolitan Electric Co.	100
Hampstead	90	St. Luke's	100
Islington	50	Clerkenwell	100
Kensington	83	Wandsworth	100

The voltage at the lamp terminals in dwelling houses is usually 100, 105 or 110 volts. There is a growing tendency at present towards pressures which are double these figures, so that voltages of 200, &c., are not uncommon. Almost all makers of incandescent lamps mark the voltage for which they are made upon the glass of the bulb. An examination of the lamps used upon a circuit will therefore indicate the voltage of the circuit; and often the candle power of the lamp and the watts (§ 39) consumed, may be learned in the same way.

The periodicity (§ 76) of alternating currents must be known before a suitable transformer (§ 70) can be selected for use on such circuits.

DESCRIPTION OF PLATES.

Plates I.—VI.

The Motor Points.

Plates VII.—XI.

The Cutaneous Nerves.

PLATE I.

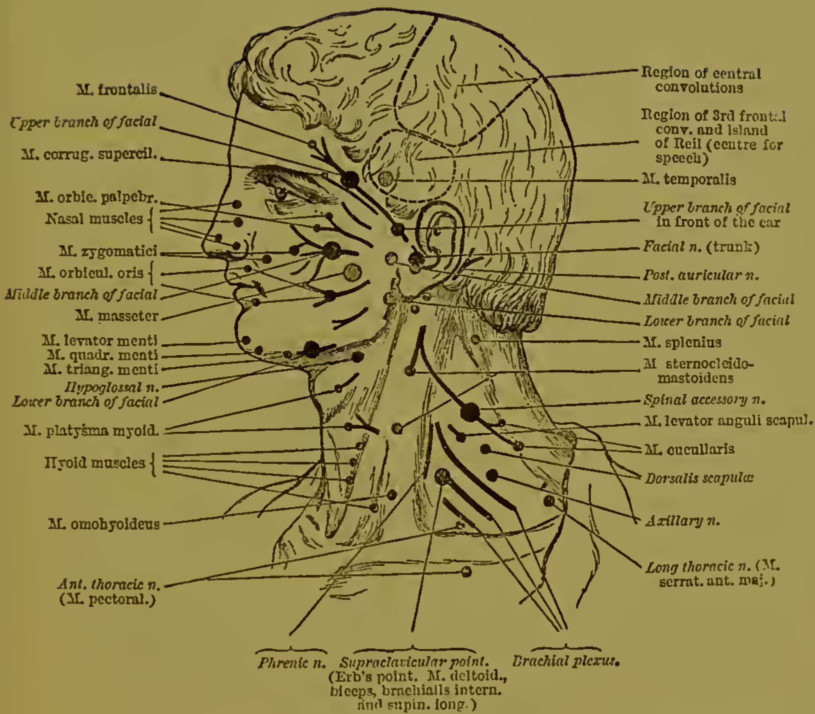

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n. (M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and Island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. cucullaris
Dorsalis scapulæ
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point. (Erb's point. M. deltoid., biceps, brachialis intern. and supin. long.)
Brachial plexus.

PLATE II.

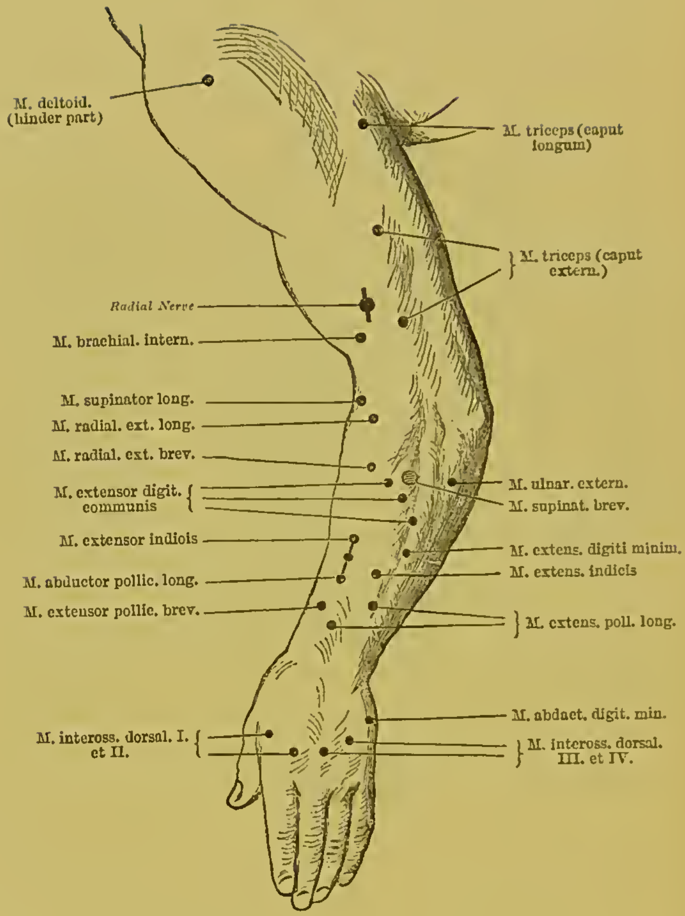
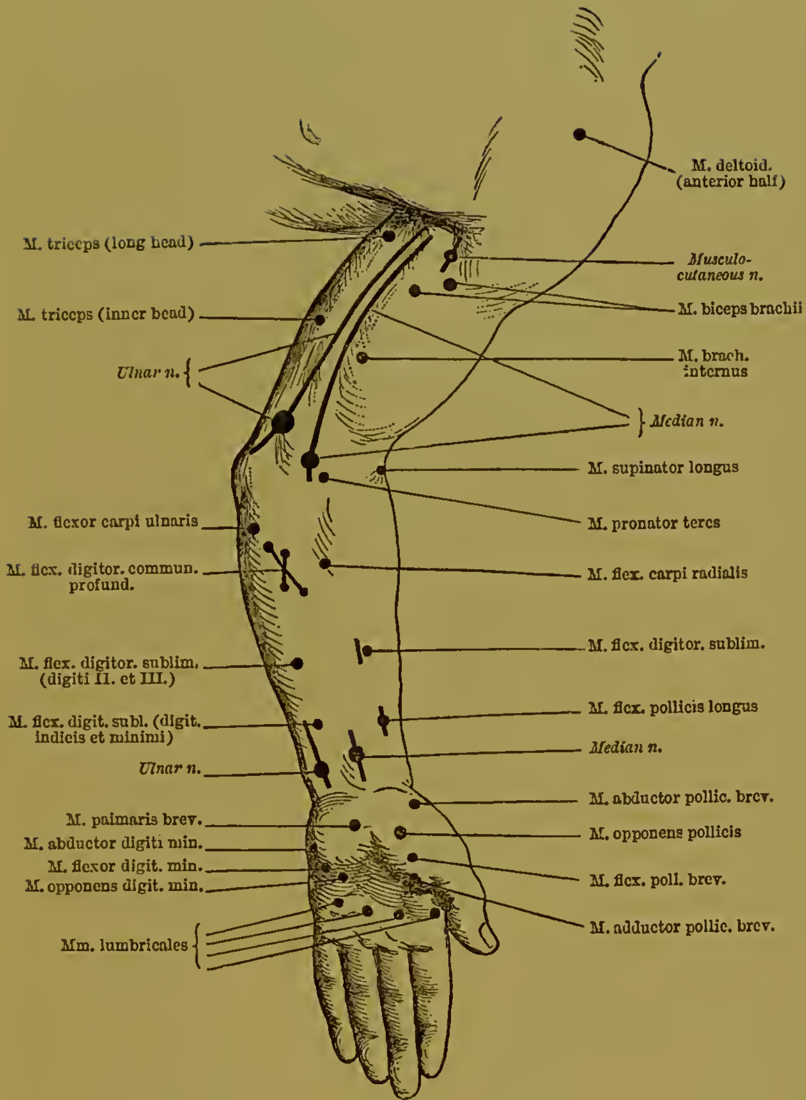
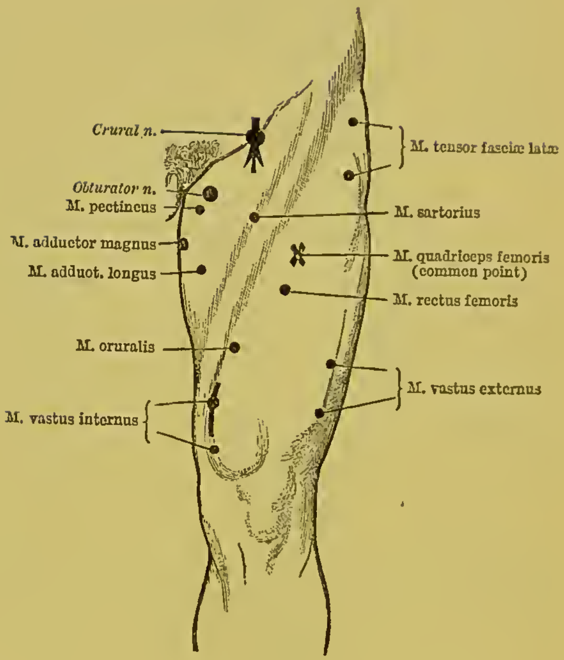

M. deltoid.
(hinder part)
M. triceps (caput
longum)
M. triceps (caput
extern.)
Radial Nerve
M. brachial. intern.
M. supinator long.
M. radial. ext. long.
M. radial. ext. brev.
M. extensor digit.
communis
M. ulnar. extern.
M. supinat. brev.
M. extensor indiois
M. extens. digiti minim.
M. extens. indicis
M. abductor pollic. long.
M. extensor pollic. brev.
M. extens. poll. long.
M. abdact. digit. min.
M. inteross. dorsal. I.
et II.
M. inteross. dorsal.
III. et IV.

PLATE III.



M. deltoid. (anterior half)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps brachii
M. triceps (inner head)
M. brach. internus
Ulnar n.
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic. brev.
M. palmaris brev.
M. opponens pollicis
M. abductor digiti min.
M. flexor digit. min.
M. flex. poll. brev.
M. opponens digit. min.
M. adductor pollic. brev.
Mm. lumbricales

PLATE IV.



Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ latæ
M. sartorius
M. quadriceps femoris (common point)
M. rectus femoris
M. vastus externus

PLATE V.

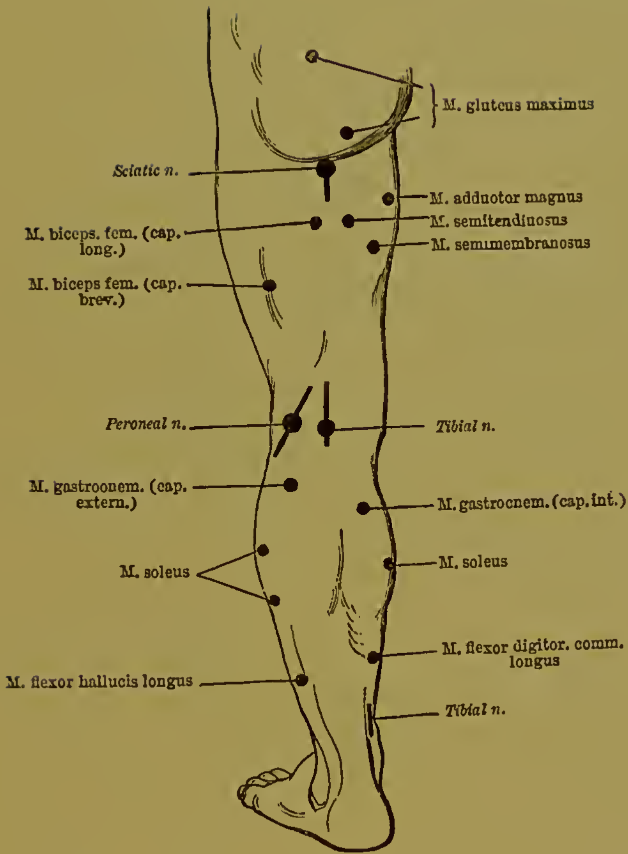
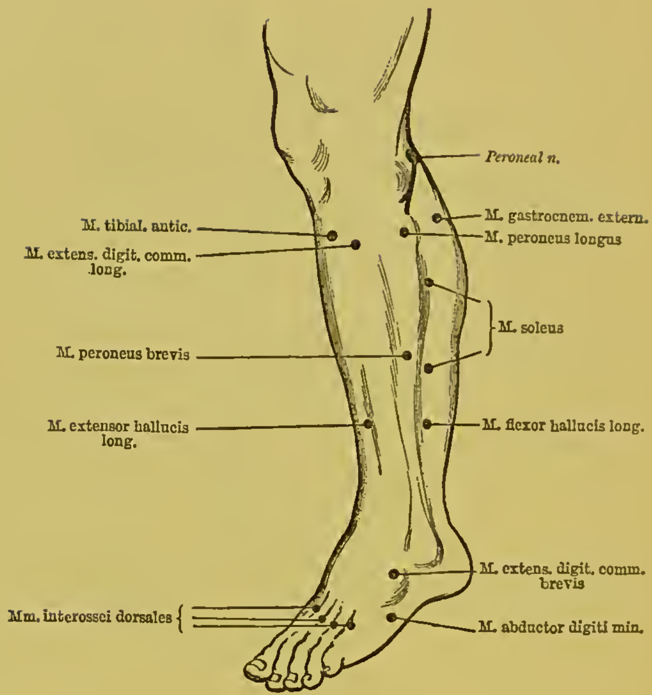

M. gluteus maximus
Sciatic n.
M. adductor magnus
M. semitendinosus
M. biceps. fem. (cap. long.)
M. semimembranosus
M. biceps fem. (cap. brev.)
Peroneal n.
Tibial n.
M. gastrocnem. (cap. extern.)
M. gastrocnem. (cap. int.)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

PLATE VI.



Peroneal n.
M. gastrocnem. extern.
M. tibial. antic.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.

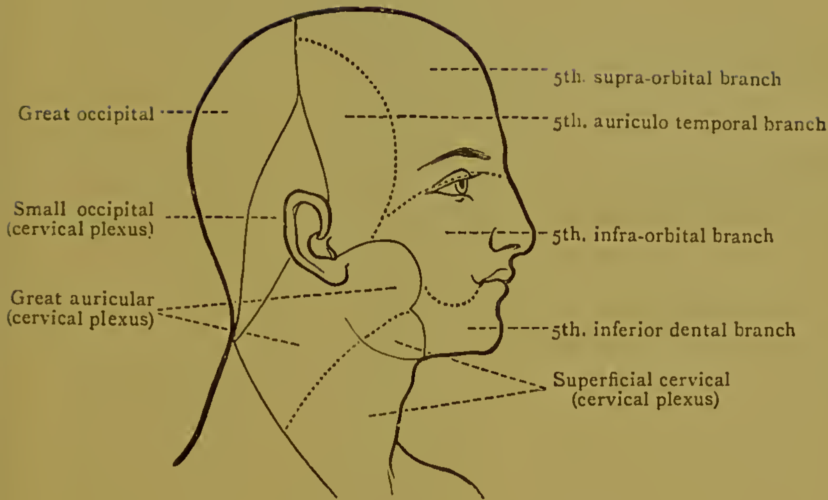
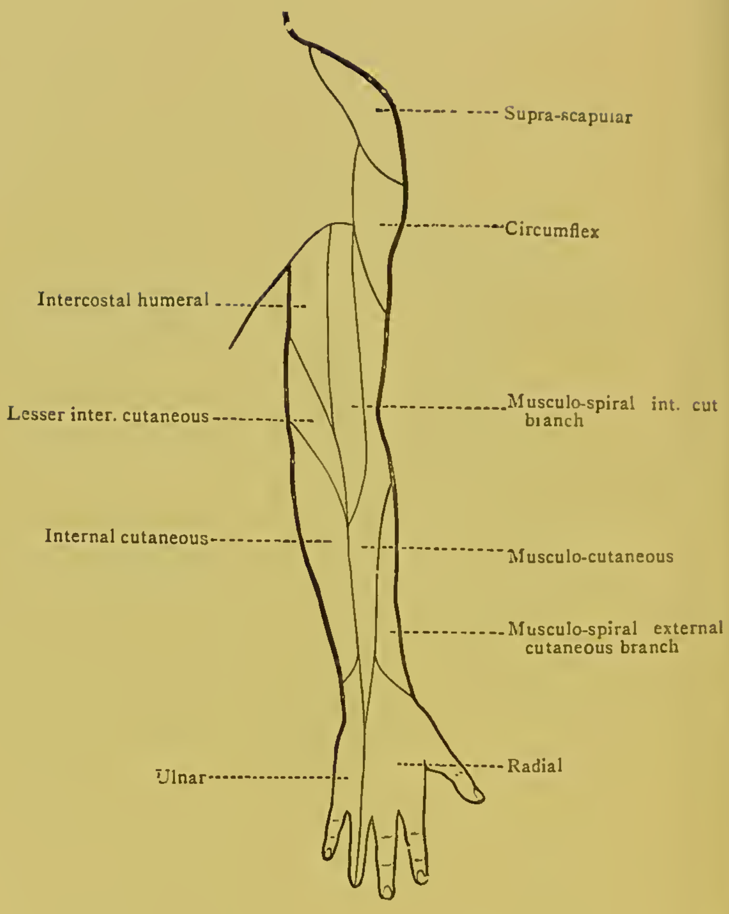
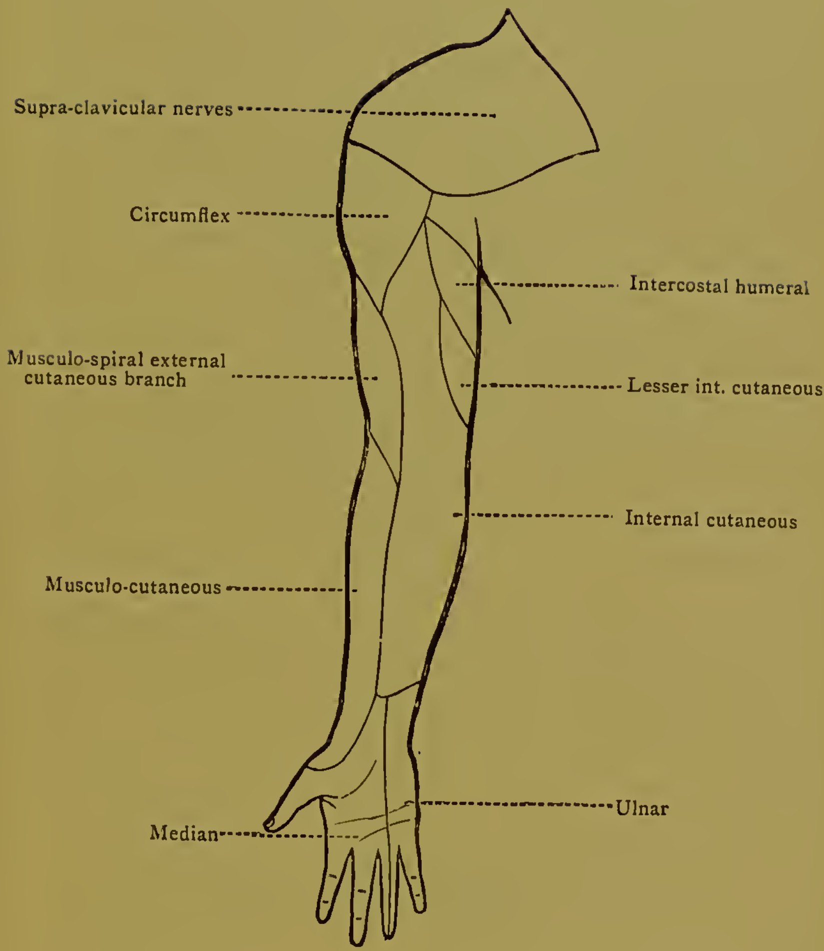

5th. supra-orbital branch
Great occipital
5th. auriculo temporal branch
Small occipital
(cervical plexus)
5th. infra-orbital branch
Great auricular
(cervical plexus)
5th. inferior dental branch
Superficial cervical
(cervical plexus)

PLATE VIII.



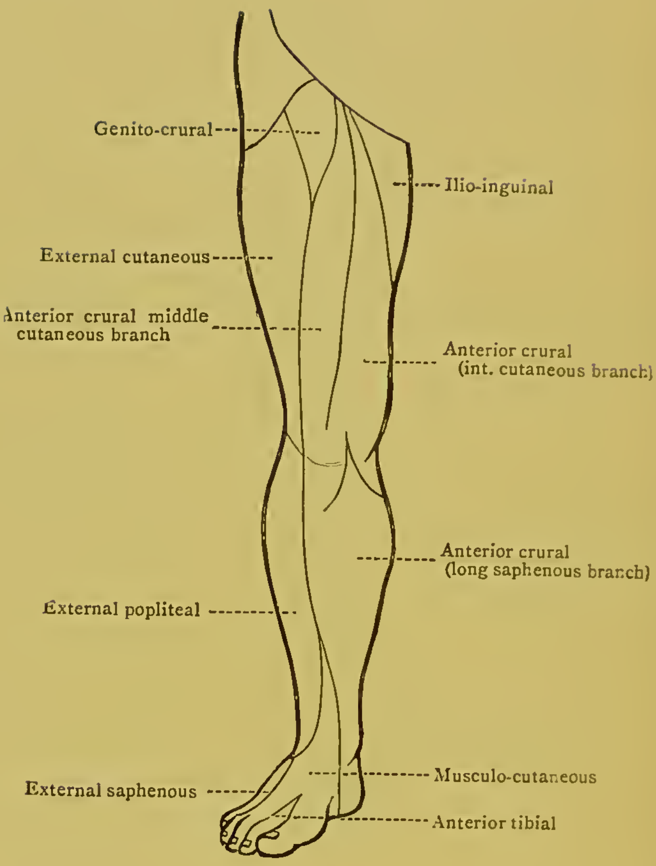
Supra-scapular
Circumflex
Intercostal humeral
Musculo-spiral int. cut branch
Lesser inter. cutaneous
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Radial
Ulnar

PLATE IX.



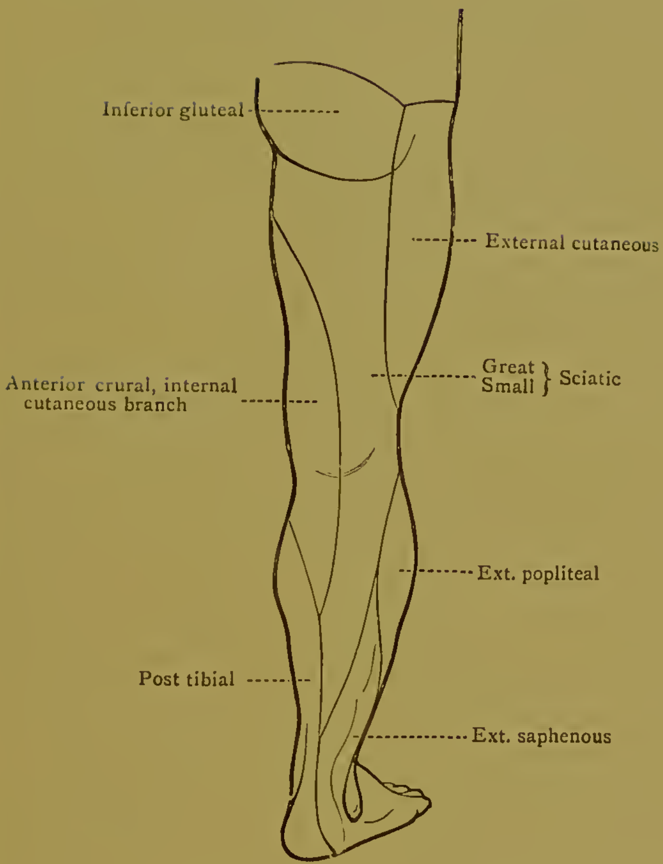
Supra-clavicular nerves
Circumflex
Intercostal humeral
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Ulnar
Median

PLATE X.



Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.


Inferior gluteal
External cutaneous
Great
Small
Sciatic
Anterior crural, internal cutaneous branch
Ext. popliteal
Post tibial
Ext. saphenous

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